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"Holistic Management of Brownfield Regeneration"

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Summary

The vision of the HOMBRE project is to accomplish "zero Brownfield (BF)" development. At present, the valuable re-use of these areas within the land-use cycle is limited. To overcome existing thresholds that limit the re-use of BFs, the project pursues a paradigm shift from short term, sectorial, and small scale (plot or building level) oriented problem solving towards sustainable (re)development of BFs. At present, single-issue approaches are most often applied, that can respond to a sites specific need, such as removal of contamination or waste management, in order to "fix" the site for a specific use or simply to comply with environmental protection legislation (e.g. urgent cases). HOMBRE, and specifically WP4 -Innovative BF Technology Trains-, will develop an approach that is based on identifying available resources and required services and goods to support the use functions of the site itself and its direct surroundings. Closing the cycles of water, materials (including soil) and energy is seen as an important process to make future use of the BF more attractive compared to its surrounding sites. Closing these cycles reduces the consumption of primary resources thereby avoiding future expends on these services and goods. Although in many cases single technologies can fulfil this objective, it is expected that combined technologies may offer better results at more acceptable costs within the desired timeframe.

The focus of HOMBRE is on the optimizing of re-use of BFs rather than on technology (combination) development. However, to optimize the re-use of BFs, a methodology is required to select those technologies that, once combined with each other or with other instruments from for example spatial planning or finance, have better results than can be expected when the technology is implemented as "stand-alone". Therefore HOMBRE will contribute to create synergies that will boost BF regeneration. In order to apply this methodology, baseline information describing the "old" BF as well as ideas regarding the "new" situation must be present. Ideas regarding the "new" situation give direction what goods and services are needed to support the use function. These goods and services should include buildings and infrastructure, water, energy and other consumables, and space (quality and quantity). We state that early collaboration between technology experts and urban architects is essential to seek and find the opportunities that BFs provide. Starting in too late a stage of development of the redevelopment project limits the possibilities. Soil and (ground)water cleanup will probably be more expensive and less sustainable, opportunities to design and construct alternative utility systems (e.g. water, energy and sanitation) will be missed as larger, collective systems need more planning, and re-using or upgrading buildings and infrastructure will be problematic. Furthermore, early cooperation gives room to include the use of "soft" technologies and intermediate land use in addition to more conventional end use oriented hard technologies. Early input of technology potential in planning BF reuse increase possibilities for costs and risks reduction. Current deliverable 4.1 presents examples of technology train design.

The main question to be answered for the successful application of technologies when dealing with sustainable BF re-development is as follows:

> What data (type, resolution) and information are needed to select technologies assisting sustainable BF re-development? And how does the data intensity relate to the ambition level of the redevelopment as set by the stakeholders of the BF especially as bounded by legislation?

This question cannot be addressed solely within WP4, and close collaboration with other work packages (especially WP2 (Roadmap to Zero BF perspective), WP3 (BF Navigator) and WP5 (Soft re-use)) is foreseen. The design of "technology trains" strongly depends on the available information on the BF characteristics, both the BF itself as well as its neighbourhood. In order to answer the research needs and to meet the objectives a dual approach is chosen. On the one hand the generic, more abstract research questions will be addressed that will help integration of the different work packages. These relate to the data requirements of the BF Navigator (BFN) and to the use of indicators as worked out in WP2. On the other hand three example technology combinations will be elaborated as a test of the generic principles of the technology trains. The actual physical testing will be on the laboratory scale, while the HOMBRE case studies will be used to test the concepts in practice.

Contents

1 Introduction work package 4

The focus of HOMBRE is put on optimizing re-use of previously zoned land in order to avoid urban sprawl. At present, the re-use of some of these areas (brownfields, BFs) is limited as development of brownfield sites is often complex, takes years to plan and deliver and requires the input of many different professions and stakeholders. Furthermore, brownfield sites have a history, sometimes a past that would be better not remembered, where contamination of the environment has virtually sterilized a site and where memories of jobs and economic stability haunt a local area (REVIT, 2007). The HOMBRE project pursues a paradigm shift from short term, sectorial, and small scale (plot or building level) oriented problem solving towards sustainable (re)development of Brownfields (BFs). Looking for synergies between sectorial techniques (e.g. within the sectors of construction, environmental remediation, energy and water) and expert fields like spatial planning, urban architecture, and finance is seen as a way to create new, unthought-of opportunities to boost BF regeneration. In the HOMBRE approach, BF's provide space and other resources that, together with so called technology trains (studied in WP4 and WP5 - Enabling BF Soft Re-use) can provide goods and services to support the future use of the area in a more effective way than it currently happens. These goods and services may be required within the BF itself or in its neighborhood/surrounding. This means that BF regeneration objectives must consider wider criteria than those strictly related to the spatial limits of the site.

At present a specific, single problem approach is most often applied that can respond to the site specific needs, i.e. removal of contamination or waste management in order to "fix" the site for a specific use, or simply to comply with environmental protection legislation (e.g. urgent cases). The HOMBRE approach is to couple this traditional approach with an approach that includes identifying the goods and services that are needed to support the "new" use of in the BF itself and/or in the neighborhood. These combined approaches make it possible to select technologies that are capable to provide goods and services in a more sustainable and effective way. For example in the case of Construction and Demolition (C&D) waste materials, these technologies can consist in techniques capable of generating high quality aggregates as a good that can be used for constructing new infrastructure or buildings.

As stated in the project proposal of HOMBRE, the objective of work package 4 is to achieve better operations, better implementations of state-of-art technologies, and to develop innovative technology-trains for sustainable, cost effective and timely regeneration of brownfields. Each BF and its regeneration is, however, unique and technology demand depends on the objectives set to each individual BF. A preliminary assessment of technology demand within brownfield regeneration resulted in the identification of three main technology categories: water (treatment) technologies, materials (recycling) technologies, and soil (cleaning) technologies. A fourth technology category, energy, was added as BF regeneration gives the opportunity to install sustainable energy systems and infrastructure to be used after regeneration of the BF. These four technology categories were combined to seek synergies within three technology trains:

1. Energy-water; directed to in situ remediation for BF regeneration in which energy and water reuse is optimized,
2. Building materials-soil; directed to optimize the reuse of materials and soil,
3. Soil-water; directed to realizing optimal soil and water management conditions.

These three technology trains are examples of technology combinations to explore synergies that can be obtained when BF regeneration is treated from a wider, holistic point of view. The workflow to achieve the objectives within the HOMBRE project is divided in 4 deliverables:

1. in depth analysis and feasibility of the technology trains
2. testing of principle of the technology trains
3. defining operating windows for technology trains
4. evaluation of the technology trains

Current deliverable 4.1 gives an overview of technologies (groups) that can be applied for BF regeneration. This overview demonstrate the feasibility of the technology trains. Before going to the technology trains themselves the embedding and role of these trains as well as their value for the process of brownfield regeneration is described in paragraph 1.1.

1.1 Background technology trains in holistic management of brownfields

1.1.1 Position of technology trains within the concept of circular land use management

Core of the HOMBRE approach is circular land management, a management approach that pre-supposes a changed land use philosophy with regard to land utilization. Land utilization can be expressed by the slogan "avoid – recycle – compensate" (proposal CIRCUSE project, 2010). Backgrounds regarding principles of circular land management can be found for example in Ferber et all., 2011[1]. In the circular land use management approach several phases of land usage are discerned as depicted in figure 1.

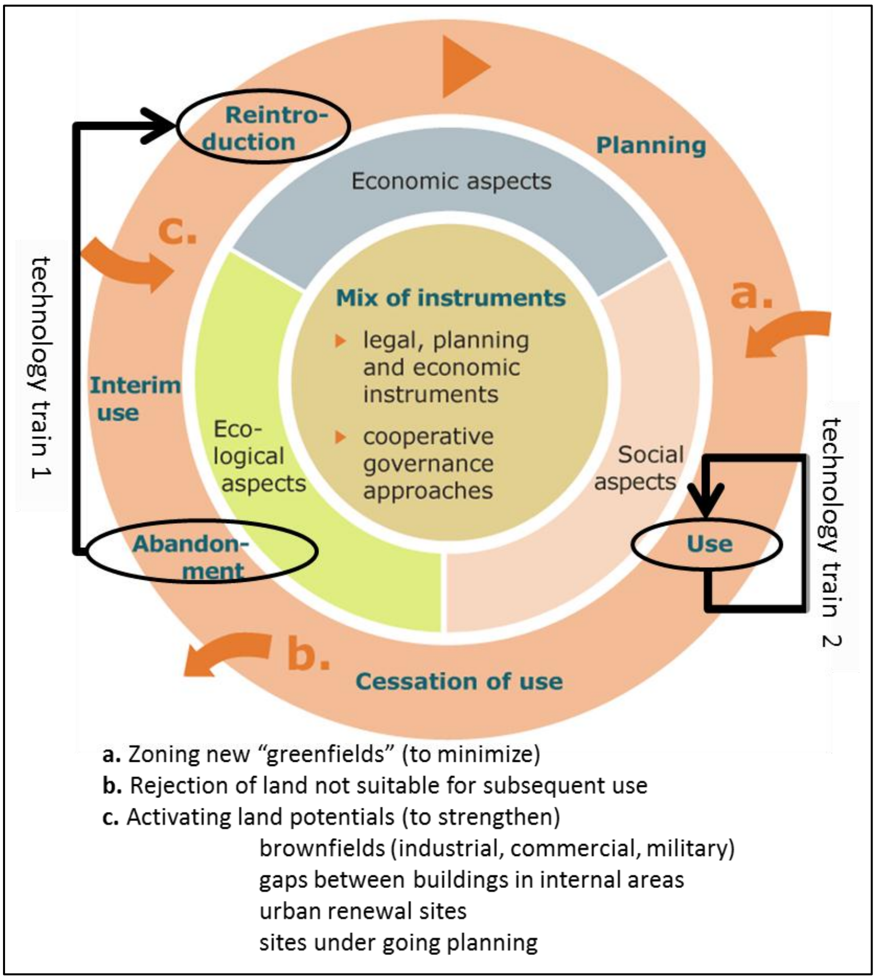


Figure 1: phases and potentialities of circular land use management (modified from Difu, German Institute of Urban affairs). The arrows are the proposed positions of technology trains: position 1 regarding BF regeneration and position 2 extending the use phase to prevent or delay BF formation

Transition from one land use phase to the next phase is regulated by driving forces that can be categorized as economic, ecological (environmental) and/or social. At this moment we assume that brownfields arise when (estimated) economic, environmental and/or social costs to continue the current use of an area are higher than its revenues/benefits or when investments are too high for stakeholders even when on the long term revenues are expected. This hypothesis needs to be fine-

[1] Ferber, Jackson, and Starzewsk-Sikorska: *Circular flow land use management in*: proceedings Real corp 2011, 18-20 may 2011, Essen, Germany.

tuned together with the other work packages in HOMBRE, especially WP2- BF Roadmap for Zero Brownfield perspective- in which indicators and criteria are explored that can be used to assess the state and/or developing direction of an area.

The persistence of brownfields depends ultimately on the expected benefits of the use phase in the next land use cycle. When benefits are expected (and risks for not reaching benefits are low), the brownfield will relatively smooth transform to a next use phase (A-type brownfields as defined in CABERNET[2]). When benefits are expected to be negative, sites will not transform to a next use phase unless a continuous flow of resources is guaranteed (C-type brownfields). When benefits are doubtful and/or when risks for not reaching benefits are high, the outcome is uncertain (B-type brownfields). Technology trains are expected to contribute to the increase of benefits (lowering the cost/benefit ration) in the "new use phase" and/or to the decrease of (real and perceived) costs in the "regeneration phase" as depicted in figure 2. Costs and benefits are thereby seen in broad perspective; not only in financial terms of currency "euro, pounds or zloty" but more in terms as expenses and gain for the environment, society and economy. Opportunities can be found through seeking synergy between, for example, technologies and spatial planning.

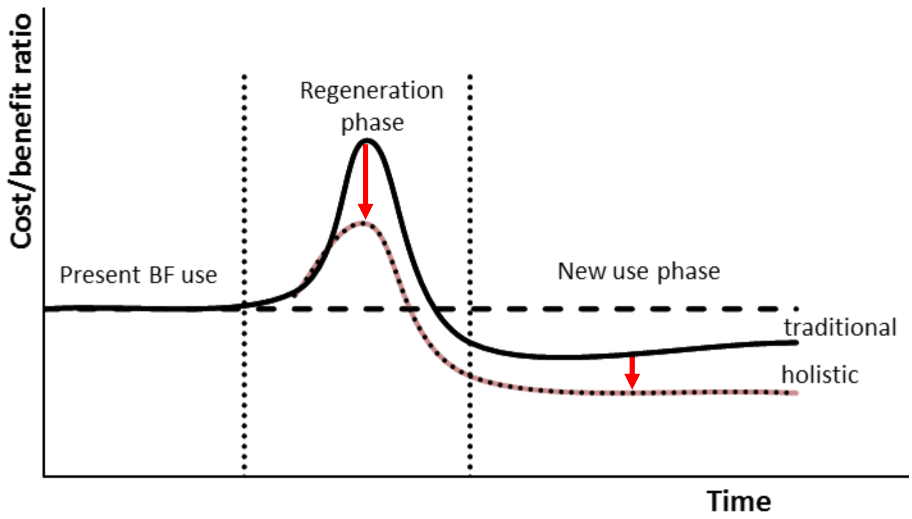


Figure 2: effects of technology trains within transition of land use phases (red arrows).

In most cases of BF regeneration, investments are needed before the new use phase commences. In figure 2 this is visualized as the temporary increase of the cost/benefit ratio compared to "do nothing" represented by the horizontal dashed line. The setup of technology trains are chosen to facilitate land re-use (train position 1 in figure 1) and maybe to extend the original land use (train position 2 in figure 1) in the two following ways:

- Red arrow in "regeneration phase": reduce investments by re-using available resources (soil and materials) and optimization of technologies (regarding time, space, and money) to improve the brownfield to a level that intended use is possible,
- Red arrow in "new use phase": lower the costs/benefit ratio for the "new use phase" either by reducing costs of energy, water and resource usage, by increasing revenues (adding activities or new land uses to the area, valorisation of environmental quality, real estate potential, and – possibly- interim use), and reducing costs of the regeneration phase (pay back costs like interest). Also providing services for surrounding area's (as is one of the directions within WP5) is such an improvement.

The advantage of this approach is the relative scale of assessment and decision making. In order to extend a sites use-phase or to re-use the site for an alternative function, it "only" requires a lower cost / benefit ratio compared to other sites nearby and the confidence of stakeholders/investors that investments in the site yield return. Absolute valued gains have no or little use in comparing sites in

[2] http://www.cabernet.org.uk/index.asp?c=1312 ABC-model

different regions or countries as local conditions such as property value, and exploitation/maintenance costs differ. Key parameters to define the technology trains that are required are available resources of the BF (the area, its state, its subsurface, its urban setting and its resources at the present situation) and the required goods and services of the BF and its surroundings to support the intended use.

1.1.2 Resources, goods and services

As stated in the previous paragraph, brownfield regeneration can be facilitated or catalyzed but not driven by technology trains. The BF's present state (its location, and environmental, spatial, economic, and social properties) provide resources that can be potentially used. Whether they can or will be used depend on the goods and services that are required to support the intended use of the site itself and its surroundings. In this deliverable we use the term "goods" for tangible resources including public goods (such as clean soil/water/air) and "services" as intangible commodities including utilities. The technology trains transform resources into goods and services that are required to support the intended function of the BF. If an area is, for example, transformed into a residential area required goods and services include buildings, infrastructure, sufficient environmental quality (goods), drinking water, heat and/or cold (services).

At present, innumerable technologies were developed that have the ability to improve the environmental quality of soil, water and atmosphere systems, to improve the efficiency of energy systems, or to re-use construction and demolishing waste products. For example, many technologies targeting soil and groundwater remediation are listed by the EURODEMO network[3], the US-EPA (CLU-IN)[4], Soilection (www.soilection.nl) in the Netherlands, or the Federal Remediation Technology Roundtable (FRTR)[5]. Also, projects like TIMBRE, Greenland, rejuvenate will deliver results that can be used. However, HOMBRE, where the focus is put on optimizing re-use of previously zoned land (brownfield) rather than on the technologies themselves provides a context or framework on how these technologies can be used beneficially. A methodology is required to select those technologies that once combined with each other or with other instruments such as spatial planning and financial engineering have better results than can be expected when the technology is implemented as "stand-alone": thus HOMBRE will contribute to create synergies that will boost BF regeneration. Performance optimization of the technology trains will be addressed using sustainability components:

- Economic: the potential to reduce costs and/or increase value of goods and services at the BF and its surrounding areas. Implementing these technologies will improve profitability (enhance the economic driver) to re-use the brownfield,
- Environmental: the potential to reduce environmental hazards such as nuisance and emissions. Implementing these technologies will enhance the environmental driver to re-use the brownfield,
- Environmental: the potential to increase the physical and chemical quality of the brownfield itself and/or its surroundings including the soil and subsurface, water and groundwater and atmosphere. Implementing these technologies will enhance the environmental driver to re-use the brownfield,
- Economic and environmental: creating value through the exploitation of renewable energy, optimized material recycling, tailored water supply and discharge, interaction and integration with the built environment, the potential to decrease the use of resources such as fossil fuels and good quality water. Implementing these technologies will specifically enhance sustainable use of the brownfield after regeneration,
- Social: the potential to adapt the technology train to match the organizational structure and management of the BF.

Aspects, such as public acceptance, legislation, and experience of stakeholders, function as boundary condition of the optimization process. The assessment of these drivers related to redeveloping BFs and preventing the development of BFs is one of the tasks elaborated in WP 2 –BF roadmap for Zero Brownfields perspective– of the HOMBRE project.

[3] http://www.eurodemo.eugris.info/SearchForm.asp
[4] http://www.clu-in.org/
[5] http://www.frtr.gov/matrix2/section3/sec3_int.html

1.1.3 Technology integration

A method to assess the optimal use of available resources to produce goods and services, is technology (or process) integration. Process integration originates from the field of chemical engineering as a holistic approach which emphasizes the unity of the process and considers the interactions between different unit operations from the outset, rather than optimising them separately in order to employ resources effectively and minimize costs. By using process integration techniques it might be possible to identify that a process can use resources rejected by another unit and reduce the overall resource consumption, even if the units themselves are not running at optimum conditions on their own: cascading. Such an opportunity would be missed with an analytical approach, as it would seek to optimize each individual unit without necessarily taking advantage of potential interactions among them (Wikipedia “process integration”). The concept of process integration is visualized in figure 3.

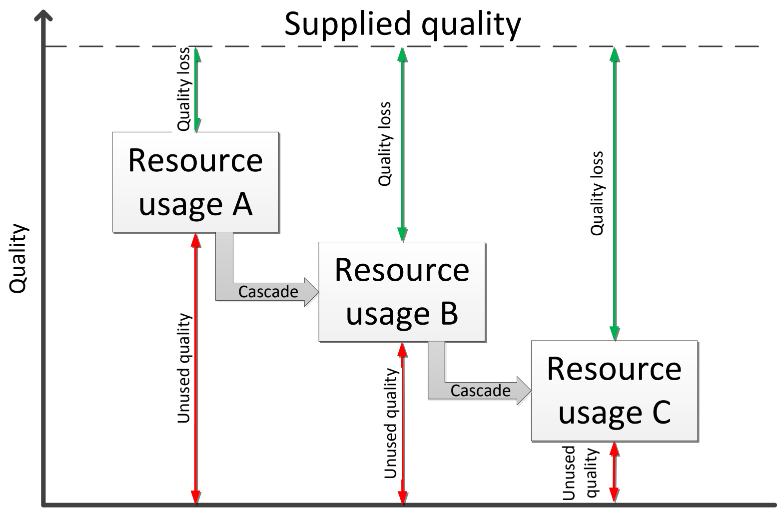


Figure 3: principle of cascading as a way of process integration. The different processes A, B, and C require resources at different quality levels; A requires the highest quality and C requires the lowest quality. In this figure the supplied resources all have a high quality even though the processes do not require such high quality: quality loss. Using the “waste” of process A as resource for process B leads to better use of the original high quality resource. Translated to the water sector this means an original supply of high quality drinking water for production of edibles (A) followed by using the waste water for crop production (B). For energy the parallel can be high pressure steam (A), followed by low pressure steam (B) followed by temperature conditioning of buildings (C).

In order to apply this methodology, information must be present regarding the goods and services that will be required to support the “new” use of the BF and resources that are available from the “old” BF. A distinction can be made between materials and soil on one hand, and water and energy on the other. Materials and soil will generally be used during the construction phase of buildings and infrastructure and remain immobile during the next use phase, whereas water and energy will be used during the use phase. The timescale to consider should therefore not be limited to the regeneration time of a BF.

Process integration of technology trains in WP4 is possible on three levels. For each level two examples are given; one for contaminated materials and one for energy:

1. **(simple) Technology train** is the combination of individual technologies (wagons) forming a technology train to provide the required service or good from a fixed (combination) of resources.
    a. Contaminated material: a technology train developed to treat contaminated soil. The wagons can be (for example): excavation, sieving or soil washing, thermal treatment of heavily contaminated fraction, landscaping low contaminated fraction, and landfilling residues. Optimization will focus on minimizing resource needs (labour, energy, space, capital) within the boundary conditions (e.g. available time, legislation, public acceptance, and organization).
    b. Energy: a technology train developed to produce electricity. The wagons can be (for example): fuel delivery, steam production, turbine technology, current control,

electricity distribution. Optimization will focus on minimizing resource needs (labour, fuel, space, capital), and maximizing electricity output within the boundary conditions (e.g. quality of service, legislation, public acceptance, and organization).

2. **Integrated Technology train** is the combination of individual technologies to provide more than one services or goods from a combination of resources. It can be expected that the efficiency (technological) of the process to produce a single service or good is lower compared to a (simple) technology train that is specialized to provide that single service or good but higher when multiple services or goods are produced.
    a. Contaminated material: a technology train developed to treat contaminated soil and other materials to provide clean building materials. The wagons can be the same as in the former technology train (1a) but where optimization will include market conditions as the most profitable inputs and outputs can be chosen.
    b. Energy: a technology train developed to use different type of fuels to provide electricity and heat. The wagons can be the same as in the former technology train (1b) but where optimization will include market conditions as the most profitable inputs and outputs can be chosen.
3. **Holistic technology train** is when we have more technology trains that can be properly integrated to provide multiple services using multiple resources for more than one sector (contaminated materials and energy). For instance the combination of Aquifer Thermal Energy Storage (ATES) and enhanced Natural Attenuation (ENA) of contaminated groundwater. Groundwater used for ATES (providing energy) can eventually positively affect ENA (providing clean (ground)water). Further integration needs however extended discussion within WP4 and eventually with WP5!

1.1.4 Hard and soft land usage

In HOMBRE, BFs intended land usage is separated between hard and soft land usage. Hard land usage is defined as land with upmarket urban, semi-urban, and industrial functions whereas soft (green) land usage is all but hard land usage. In WP4 the focus is put on developing innovative technology trains for the regeneration of the hard land use functions. The rationale is to make BF rapidly fit for use while considering sustainable regeneration and after use. Fit for use means acceptable risks for the intended function of the BF and is related to e.g. contaminated (ground)water, building materials, soil, and other residues like mining debris.

Soft re-use will be the focus of WP5 of the HOMBRE project and is pointed towards enabling the usage of BF for green uses such as biomass production to assist urban living. The soft re-use concept is complementing the solutions developed within the technology train concept as developed in WP4.

In some cases, combining hard and soft land use can be beneficial to reduce redevelopment costs and to optimize the production of goods and services. For example, in the case of soil or groundwater contamination with contaminant levels that pose a risk for residential functions, using the area for biomass production can reduce the chance of contact between contaminant and inhabitants, thereby reducing the risk for human exposure. Furthermore, if the contaminants can be attenuated by natural processes within a timeframe of decades, it is possible to use that specific area for residential functions when needed. Green land use can then be seen as interim use that produces services while improving the quality of the area or finding a solution for a challenge that cannot be addressed in a specific timeframe.

Another example can be given for the water system. Especially in urban areas, where land sealing prevents infiltration of water, small periods of heavy rainfall lead to a sudden availability of large amounts of water. Flooding (and mud streams) can be the outcome when the water discharge system has insufficient capacity. Assigning areas, (a part of) the BF to temporally store the water for later use or slow release, reduce the risks of flooding at surrounding (downstream) areas. Investments and land demand that traditionally are required to protect the downstream areas against flooding can be reduced or even avoided.

Early collaboration of BF redevelopers, landscape architects, spatial planning specialists, and technology specialist maximizes the opportunities to achieve sustainable, cost effective, and timely regeneration of BFs.

1.1.5 Operating windows

Operating windows for technology trains are part of the methodology to select optimal technology combinations when needed. Operating windows are defined by the boundaries (upper and lower) of critical parameters of a technology where certain failure modes are excited (Taguchi, 1993). Integration of these critical parameters result in the operating window of the technology that is addressed. Combining technologies will lead to a large increase of parameters that need to be addressed to define the operating window of the technology train. Robust design equals a large operating window. In HOMBRE the focus is however not on a specific technology or a combination of technologies but on instruments and tools that can solve real or perceived obstacles that currently prevent brownfield regeneration. On that abstraction level critical parameters need to be found/addressed that strongly relate to the experiences of BF managers, decision makers, property owners and investors, and regulators; in other words: to the stakeholders of the BF. Parameters like space, time, money, and policy are therefore the preliminary, first choice.

Operating windows for the (combination of) technologies must however comply to the frame that is set by social, economic, and environmental aspects on a specific site. For example, when a BF is located in a country/region that does not allow risk-based soil and groundwater remediation, only technologies targeting contaminant removal can be applied before the site can be re-used. Synergy with for example soft-land use concepts is in that case unlikely. A similar frame is expected for the re-use of C&D waste. Another example can be given for a BF with multiple property owners. A comprehensive BF approach is unlikely when a single owner is not willing to cooperate. The operating windows of technology trains for BF regeneration will be more thoroughly addressed in deliverable 4.3.

1.2 Goals of technology trains in holistic management of brownfields

1.2.1 Research needs

As will be shown in the technology train chapters (2, 3, and 4) an innumerable amount of technologies exist that are capable to remediate soil and water, produce energy, or to re-use building materials. Also, many initiatives were started to support technology selection for a specific goal. However, the integration of technologies to provide goods and services for multiple sectors such as water and energy, soil and building materials, while putting focus on the context (the BF itself) is still underdeveloped. The main question to be answered for the successful application of technologies when dealing with sustainable BF re-development is as follows:

> What data (type, resolution) and information are needed to select technologies assisting sustainable BF re-development? And how does the data intensity relate to the ambition level of the redevelopment as set by the stakeholders of the BF?

This question cannot be addressed solely within our work package 4, and close collaboration with other work packages (especially WP2 (roadmap to zero BF perspective), WP3 (BF navigator) and WP5 (soft re-use)) is foreseen. The design of “technology trains” to close the energy, water, and mass (resources) cycles as much as possible for acceptable costs and within a desired timeframe strongly depends on the available information of the BF characteristics, both the BF itself as well as its neighborhood/surrounding. Effective tools are needed to evaluate performance of designed “technology train’s”. Moreover, in time, additional technologies are developed and need to be ‘uploaded’ into the technology suite that is offered to the end user (ref. WP3).

Next to this rather abstract research question, the transfer of knowledge and experience between countries involved in the HOMBRE project, thematic/sectorial experts, and stakeholders of the HOMBRE cases can be seen as a critical need to set the next step towards sustainable redevelopment of BFs.

1.2.2 Objectives

In the HOMBRE approach, the BF becomes an opportunity to provide services and goods to support the use of the BF in a more effective way than it currently happens. This means that the approach to the BF regeneration must go beyond the individual BF site and has to look on a wider scale (local or even regional). This also means that the approach in the choice of the best BF regeneration pathway must go beyond business as usual, where the priority lies in selecting a series of technologies (supposed to be the Best Available Technologies (BATs)) that can respond to the sites specific needs. For example, the removal of contamination or waste management in order to “fix” the site for a specific use, or simply to comply with environmental protection legislation (urgent cases etc.). HOMBRE, and specifically WP4 -Innovative BF Technology Trains-, will develop an approach that is based on identifying available resources and required services and goods to support the use functions of the site itself and its direct surroundings. Closing the cycles of water, materials (including soil) and energy is seen as an important process to make future use of the BF more attractive compared to its surrounding sites. Closing these cycles reduces the consumption of primary resources thereby avoiding future expends on these services and goods. Although in many cases single technologies can fulfill this gap, it is expected that combining technologies have better results (cheaper, faster, more acceptable, and/or less risks).

The main objective for WP 4 (and 5) is the inclusion of technology (trains) in the decision and planning process of brownfield regeneration to enlarge (the number of) possible functions, goods and services of brownfields that were otherwise not considered. Understanding these possibilities increases the chance that a brownfield will be re-used rather than avoided.

1.2.3 Methodology

In order to answer the research needs and to meet the objectives, a dual approach is chosen. On the one hand the generic, more abstract research questions will be addressed that will help integration of the different work packages. These relate to the data requirements of the BFN and to the use of the criteria and indicators as set in WP2. On the other hand three specific technology combinations will be elaborated to test the generic principles of the technology trains. These three technology combinations are the following:

1. Energy-water: Aquifer Thermal Energy Storage combined with contaminated aquifer remediation and heat/cold collection from the water system (mainly desk study combined with occasional lab experiments)
2. Building materials-soil: Carbonation combined with granulation and Stabilization/Solidification (mainly lab experiments)
3. Soil-water: In-situ carbonation of soil to improve mechanical soil properties and construct a vapors barrier while stripping contaminants (mainly lab experiments)

The HOMBRE BF cases will primarily be used to guide the development of the generic technology train concept in relation with the data requirements. BFs that comply to the boundaries of WP4 (redevelopment of residential, office or industrial buildings, presence of contaminants in soil, aquifer or surface water, and availability of C&D waste) are Solec, Genoa, and Terni.

This deliverable 4.1 gives an overview of technologies (groups) that can be applied for BF regeneration. The choice for the three specific technology combinations as examples of the technology trains is arbitrary and will not be elaborated in this deliverable. Moreover, one can design more ‘trains’ with present information. These present trains are set as example and application in the cases mentioned to test feasibility of the methodology. The present train suite is not exhaustive.

2 Technology train energy and water

2.1 Introduction energy and water: specific BF problems

At the time that many of the current BFs were initially developed or zoned, generally before the 1970's, energy (or better, resources for energy production) and water were not considered to be limited resources. Development of these sites was therefore directed to provide goods and services that were required for the intended usage, e.g. infrastructure, energy- and water, housing (residential and/or offices), etc. These goods were basically consumed and, after usage, disposed. As energy and water were considered to be unlimitedly available, no economic drive was present to minimize and reuse these resources.

Starting in the 1970's, an increased awareness can be distinguished regarding the scarcity of resources, including energy and ("clean") water. Recognizing the scarcity of these resources, together with increasing costs of disposal (of waste products) due to stricter environmental regulations, provides an economic drive to reduce energy and water consumption. Reduction of energy and water usage can be obtained by increasing the efficiency of the (industrial) processes (lower the quantity of waste streams) and by recycling the waste streams.

Although inefficient energy and water usage may play a limited role in the creation of new brownfields and in the regeneration process of brownfields (as environmental and economic driver), the regeneration process provides an opportunity to include sustainable energy concepts and water systems. A joint effort of spatial planners, financial and technology experts can lead to optimal conditions to design sustainable areas by "pre-engineering" the site. Pre-engineering means to include crude calculations based on estimates, national or local average values or experiences regarding the water, energy (and other) requirements (services) in the spatial planning process. The main goal is to avoid "decisions of regret", those decisions that may be beneficial on a short timescale but are costly on the long run or that prevent the development of alternative, better options. The return on investments of water and energy structures made in the regeneration phase will be expected in the use phase. Feasibility assessment of energy and water technology trains is the core of technology train 1.

The first step in the feasibility assessment of energy and water technology trains is a description of potentially available resources and required services of energy and water on any (selected) brownfield.

2.1.1 Water resources and services

BF problems that are associated with the water system can relate to water quality (contamination) and water quantity (too much may lead to flooding, too less may lead to use restrictions or draught). Determination of problems requires information on both the available resources and required services in time. Water quality is a problem when high quality water is required but low quality water is available or when contaminated water (ground or surface water) forms a risk for users and ecosystems (receptors) of the BF and its surroundings. Water quantity is a problem when the inflow of water (precipitation, groundwater, surface water) at certain times exceeds the outflow of water (drainage, sewers, canals, etc.) or when the amount of required water is higher than the available amount of water.

Potential resources and required services of water on existing brownfields are summarized in figure 4. It depends on the BF location which resources are present and which services are required. Although the availability of resources and required services may change in time when a brownfield is regenerated, infrastructure related to the water system may be re-used, especially when structural parts of the brownfield remain. The quality of available water resources is variable in time, depends on the source and is area specific. The quality of waste water depends mainly on the processes where water is disregarded and is therefore system specific. Quality of ground water and surface water depends largely on the contaminant level of the brownfield itself, the (hydro) geology of the brownfield and the upstream water quality. Quality of precipitated water is expected to vary between good and poor and depends on regional (or national) contaminant sources.

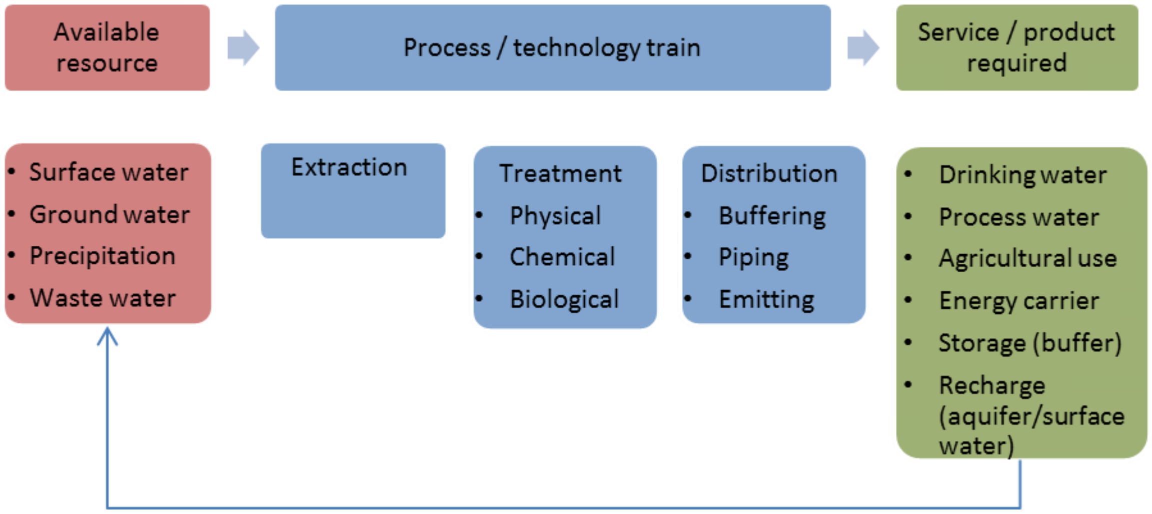


Figure 4: Water resources and services on BF

The required good or services mainly depend of the intended land use function after regeneration of the brownfield. Ideally, detailed data of future water use (both quality and quantity) is available but in most cases the intended use of the brownfield after regeneration is not known. For the exploration of possible, future use of the brownfield, and the related water consumption, usage of indicative values will be required. After the water is used, it becomes a waste stream that can again be used as a resource. Transformation of available resources into required services is performed through the technology trains. These technologies will be elaborated in paragraph 2.2.1.

The quantity of water demand for distinctive water quality categories is highly variable between European countries and, for commercial and industrial functions, strongly dependent on the type of commercial or industrial function. Water usage by domestic, commercial and industrial sectors can be found, for example, at Eurostat and national statistical agencies. For an estimation of (future) water demand, quantities with units m^3/area or m^3/dwelling can be used for all categories of water quality. Data available on Eurostat[6] (absolute water consumption per user category and land use per user category) give, after some re-ordering, for example the following indicative values (situation around the year 2007, between brackets (n=) the number of countries with sufficient data):

- Residential areas: average water usage between 807 m^3/ha (Greece) and 5616 m^3/ha (Spain) (n=8). The fraction of public water supply was 99%. The remaining 1% originate from (local) ground or surface water abstraction.
- Manufacturing industrial areas: average water usage between 7500 m^3/ha (Poland) and 55600 m^3/ha (Netherlands) (n=4). Water usage is especially high in chemical and refined petroleum industry. The fraction of public water supply was 11%. The remaining 89% originate from (local) ground or surface water abstraction.
- Agricultural areas: average water usage between 3 m^3/ha (Bulgaria) and 1776 m^3/ha (Malta) (n=14). The fraction of public water supply was 2%. The remaining 98% originate from (local) ground or surface water abstraction.
- Mining/Quarrying areas: average water usage between 429 m^3/ha (Sweden) and 9700 m^3/ha (Belgium) (n=6). The fraction of public water supply was 3%. The remaining 97% originate from (local) ground or surface water abstraction.

Although the available information is limited, it is possible to make the following observations: residential areas require good water quality (drinking water) which is almost exclusively (99%) provided by public water suppliers. This good quality drinking water is used partly for the required service "drinking water" but also for services that do not need this high quality such as toilet flushing, laundry and washing, cleaning, etc. The quantity of water used in residential areas is lower than in manufacturing industrial areas although the quantity of water supplied by public water suppliers is higher. Data regarding commercial usage was not available at Eurostat. These findings imply that brownfield regeneration from industrial to residential use will (on average) lead to a decrease of total

[6] http://epp.eurostat.ec.europa.eu/portal/page/portal/environment/data/main_tables

water use but to an increase of required water quality. The water supply network will therefore be restructured, providing opportunities for more sustainable water use.

Besides the availability of water as a resource for services, it also can be a hazard that affects the BFs and neighboring users. Especially in urban areas, where large fractions of the earth surface is sealed, a period of heavy precipitation leads to high water flow rates resulting in flooding or mud streams when the drainage capacity is exceeded. A service on BF level that can be thought of is the buffering of water to prevent flooding of downstream areas (soft land use).

2.1.2 Energy resources and services

BF problems associated with the energy system relate to inefficient energy production and consumption, and thus high costs for energy use, and (possibly) the city heat island effect. Solving these problems will not so much catalyze the threshold that prevent BF regeneration (the activation energy) but can provide an opportunity to enhance the economic driver to re-use the BF. Possible resources of energy on existing brownfields and required services are summarized in figure 5. It depends on the BF location which resources are available and which services are required. The availability of resources and required services may change when a brownfield is regenerated.

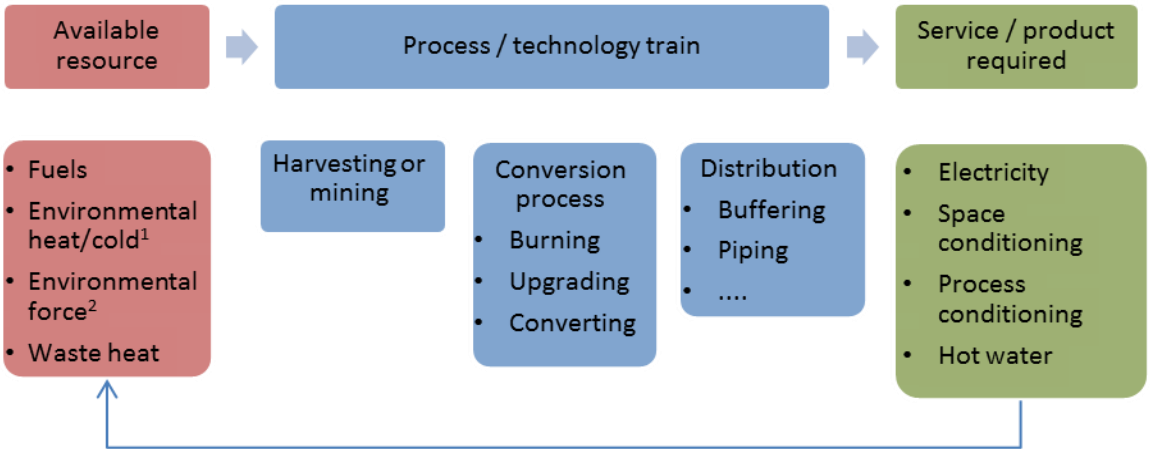
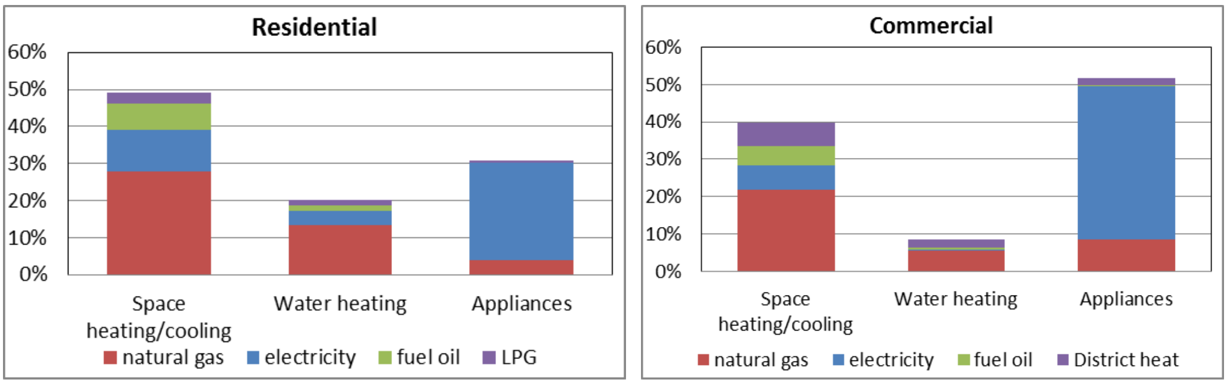


Figure 5: Energy resources and services on BF.

[1] environmental heat/cold includes geothermal, solar thermal, water thermal, and air thermal energy.

[2] Environmental force includes wind power, hydropower and solar power (PV) that can be converted to electricity.

The energy demand that is required at a site varies highly with the intended functions of a brownfield, and depends on the local climate of the brownfield. In figure 6 the distribution of energy end-use is given for average (countrywide) residential areas, commercial areas, and industrial areas in the US. Besides the distribution of end-use, also the energy carrier is given.



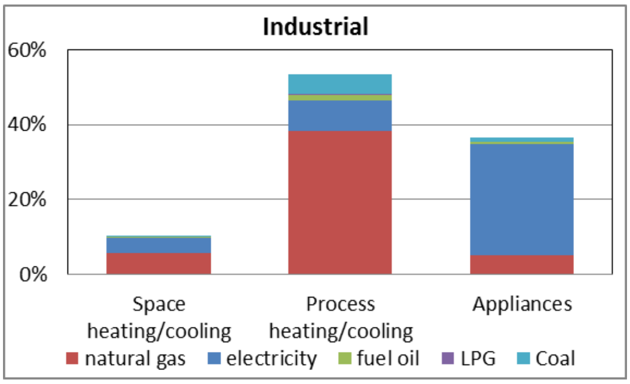


Figure 6: energy consumption by end-use and energy source for residential, commercial, and industrial functions (residential modified from US-EIA, 2010, commercial modified from US-DOE/EIA, 1994, industrial modified from US-EIA, 2006)

In figure 6 it is clear that space conditioning (heating and cooling) accounts for half of the energy demand (ca. 40-50%) in residential and commercial functions, and only for a fraction of the energy demand in industrial functions. From an exergy point of view, the use of natural gas, fuel oil and LPG for these low temperature heat demands is not efficient. Exergy is the energy that is available for use. Fossil fuels (natural gas, oil, and coal) have a high caloric content (exergy) that makes it possible to generate temperatures (much) higher than required. Using these fuels for spatial heating will therefore lead to “loss of quality” as depicted in figure 3 (resource C). Efficiency, and thereby a more efficient use of resources, can be increased by using low caloric heat from the surrounding environment or by using waste heat that becomes available as a resource after performing other (energy) services.

Transformation of available resources into required goods and services is performed through the technology trains. BF regeneration offers opportunities to lower the energy demand by improving old, existing buildings and building new, low energy consuming buildings. Besides, the opportunity can be taken to install systems that harvest the environmental energy resources to make the (long term exploitation) costs lower. By doing so, an environmental and economic driver is enhanced that make future (re-)use of the BF more likely.

2.2 Individual technologies currently used

At present, innumerous amounts of technologies exists (both novel as proven) that are able to convert available resources into required services. Listing these technologies is not the goal of this paragraph and (probably) does not help understanding the opportunities that brownfields provide to deliver required services. In this paragraph basic technology concepts are presented that may play a role in the construction of technology trains. As stated in the previous paragraphs and chapters, technologies can only be assessed when both the available resource and the required service are considered.

2.2.1 Water technologies

Technologies regarding the water system (drinking water, process water, waste water) mainly involve the production of water meeting the required quality for use or legal quality to dispose. The costs of water use and the costs of water disposal are the main economic drivers for application of reuse technologies.

Water production technologies are designed to extract water from its source (e.g. surface water, aquifers, and precipitation), make the water fit for use and distribute the water to the consumers. Technologies that are used in these steps depend mainly to the water quality of the source and the required water quality, and include pumping, water treatment (desalinization, filtering through sand bed or membranes, disinfection, aeration, etc.) and distribution (buffering, piping, monitoring). Improvements of water production technologies target the reduction of water spillage through implementing better distribution networks, and reduction of costs of the water treatment facilities.

In areas where contaminated ground or surface water is extracted for use, costs for cleaning water is relatively high as more effort is required to remove contaminants and to monitor the effluent quality. Depending on the availability of other water sources (e.g. public water supply), it becomes beneficial to switch the water supply and buy water from a water supplier. Disadvantages are the dependency of the (most often) monopolistic supplier, the purchase of single (high) quality water for all uses and an increase of risk of contaminant spreading.

Waste water treatment systems are designed to remove (macro) contaminants from the water stream before emitting it to the receiving water system. The contaminants that are removed from the water phase, either by degradation or phase separation, lead to a more concentrated waste-stream. Roughly the technologies that are used can be categorized in biological (e.g. aerobic or anaerobic) active treatment systems, physical/chemical treatment (e.g. adding oxidants/reductants) systems and phase separation (e.g. membranes or sedimentation/flotation) systems. Water re-use technologies mainly focus on polishing steps to upgrade the quality of effluent from the waste water treatment. Specific problems, like the buildup of minerals, are currently addressed in many (scientific) studies.

Precipitation and risks for flooding are currently addressed by installing infiltration facilities, temporal water storage facilities (e.g. ponds and other works as shown in figure 7) and dams and dikes. Most of these facilities are civil technologies. In the Netherlands, area based approach development programs are tested on their effect on the water system. The main idea is that sealing the earth surface may not lead to additional removal of water from the area to its surroundings as periods of heavy rain makes the water burden of the surface waters already high. An additional flux of water into the surface water system may in that case lead to flooding risks down streams. Furthermore the additional removal of water in wet, rainy periods increases the chance of draught in dry periods. Priority is given to infiltration of water into the subsurface, followed by temporal water storage and finally active removal towards the surface water system.

Figure 7: examples of water storage in urban areas (left Amsterdam, right Rotterdam)

2.2.2 Energy production technologies

Technologies regarding the energy system (electricity, steam, heat, cold) mainly involve the production and distribution of these services. Starting from different resources the generic process is the production of high caloric heat that can be used either for heating spaces and water for direct usage or to produce steam for power generation. A diagram presenting electricity, heat and steam production from various resources is given in figure 8.

Traditionally, fossil fuels like coal, oil, and natural gas are combusted in an oven to produce high caloric heat. This heat is required to transfer the condensate (often water) into vapor (steam). In a turbine, the energy of the vapor is extracted and converted into useful work. The vapor will again be transformed into condensate while the work is converted into electricity using the generator. Typical efficiencies of such an electricity power plant is around 40% electricity and 60% (waste) heat.

The use of fossil fuels for electricity production has however some important drawbacks. Fossil fuels are not sustainable as regeneration rates of these materials are much lower than present consumption rates. Although worldwide proven reserves of coal are more than enough for several centuries of usage, oil mining industries are facing more difficulties to extract the oil from the earth crust, leading to an increase of costs. Currently the gas price is (artificially) coupled to the oil price and therefore also gas prices increase. Furthermore, fossil fuels are generally not pure. The presence of other compounds, for example metal sulfides, lead to contaminated exhaust gases (sulfur dioxide) and ashes (metals). Preventing these contaminants entering the environment requires additional investments of green technologies (gas treatment) and a controlled waste disposal pathway. The latter will be discussed in technology train 2 (materials and soils).

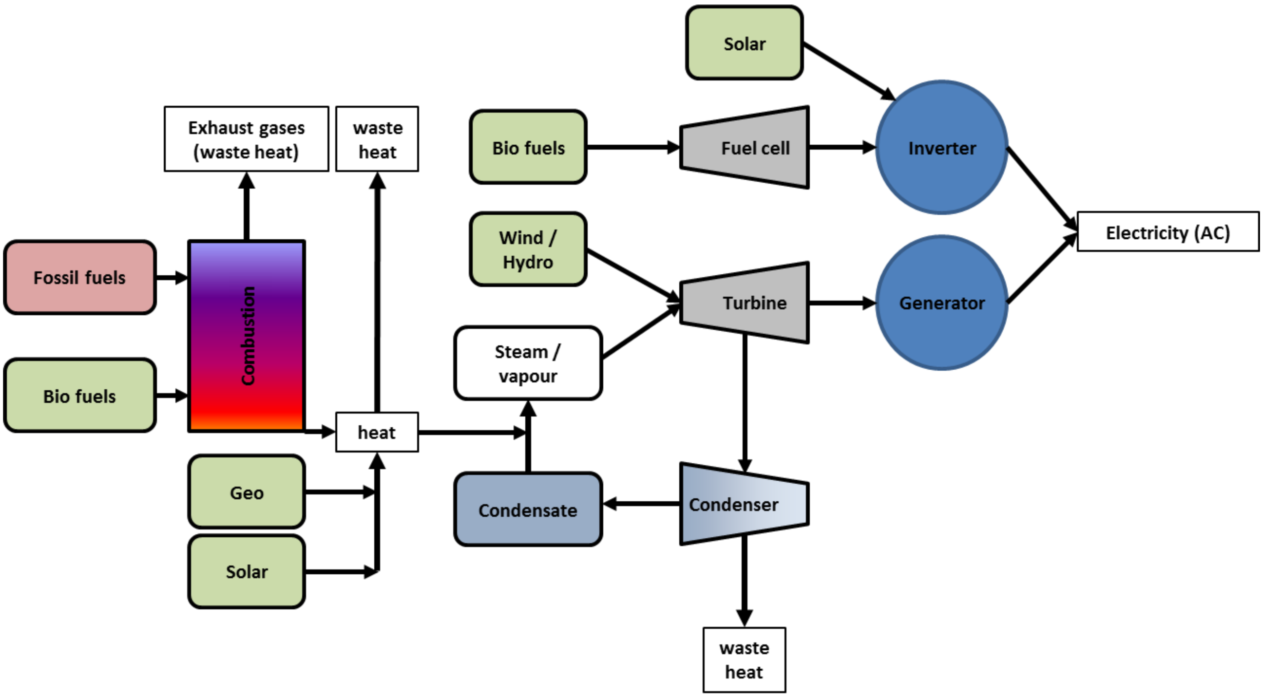


Figure 8: Diagram of electricity, heat and steam production from various sources (green blocks)

More recently, alternative resources are used to produce heat. Among these alternatives are bio-fuels (in principle renewable and not coupled to oil prices but have lower caloric values and are often competing with food production) and environmental heat sources (geothermal and solar). The main advantages of these environmental heat sources are the independency of oil prices and the absence of a combustion process. In contrast to the use of fuels (fossil and biomass) that can easily be transported in bulk quantities without loss of energy content, the use of environmental heat sources is site specific. Heat production and consumption need to be close together as during transport heat is lost. Technologies involved in electricity production based on heat are as follows:

- Geothermal: wells (depth down to 5 km below surface) are installed to harvest steam directly (dry steam technology that directly makes the turbine working) or hot water. The majority of geothermal power plants (>90%) pump up hot water. Two distinct technologies are currently used to convert the hot water into a working vapor to drive the turbine. Flash steam technology, that requires water temperatures > 175 °C, produces steam by lowering the pressure and binary cycle technologies that use heat exchangers to transfer heat to a secondary circuit where alternative working fluids can be used. With binary cycle technologies water temperatures as low as 90 °C can be used. The cooled water is then re-injected into the geothermal reservoir to maintain its pressure. The lifetime of a geothermal reservoir depends strongly on regeneration of heat. In volcanic active areas regeneration is more likely than in other areas. When no regeneration occurs typical life times of 30 years are reported. At this moment, geothermal electricity production is reported by 24 countries worldwide, including Italy, France, Portugal, Germany, and Austria.
- Solar: efficient electricity production from solar heat requires high temperatures (>>200°C). Direct solar irradiation on the earth surface is insufficient and needs to be concentrated using a technique called concentrated solar power. This technique uses mirrors or lenses, to focus

the solar radiation on a specific point to heat water or salts. Obviously the use of solar thermal energy for electricity production benefits from a sunny climate. At this moment, solar thermal electricity production is reported by 2 countries worldwide: Spain and USA.

Figure 9: Left: artist impression of a geothermal electric powerplant (taken from energy-green.net); Right: concentrated solar electric plant Solúcar PS10 (taken from Wikipedia)

Main disadvantages of these technologies are related to economic aspects. The majority of costs are made before actual electricity production starts while the price of electricity is not fixed but relates to prices of other electricity producing plants. A long term prognoses of electricity consumption and electricity prices is essential to assess the benefits of investments. Furthermore, especially for geothermal electricity production, risks of project failure are significantly as local properties of the deep sub-soil are not well known. The scale of these technologies and the risks of failure are such that only few companies can bare the required investments and insurances.

Besides using heat for electricity production, it can also be used directly to heat spaces (district heating), processes, and cooling. A technique capable to convert heat into cold is an absorption heat pump. Using heat significantly increases the energy efficiency. However the distribution networks require attention in the design (space needs to be available to transport heat to the consumers and back) and buffering. Also investment costs are relatively high, especially for transport of high temperature heat. Including the heat networks in the planning of brownfield regeneration process make efficient systems (economic and energetic) more likely.

Direct electricity production can be obtained by using work of environmental sources such as wind and water (hydro). Together with a generator, a turbine can directly convert wind and hydro energy into electricity. Boundary conditions are the presence of sufficient wind at a site (wind strength and variability) or sufficient gravitational force of water (flow rate and head). Wind and hydro electricity production is nowadays standard and proven technology worldwide. Costs of electricity for consumers are comparable with market prices. Disadvantage for wind power is the variability of the resource. Studies in Denmark showed however that up to 20% of total electricity production by wind power will not lead to stability problems of the nationwide electricity supply. Spatially the wind mills need to be zoned because of noise, shadow, and risks of collapse. Urban functions within these zones are not likely. For hydropower the variability of electricity production is lower than wind power. However to increase the reliability of production some buffering (e.g. buffer lakes) are constructed. The scale of both wind- and hydro power varies from very small (<1 MW) to very large (wind farms > 400 MW, Three Gorges dam> 22 GW). Risks and investments vary accordingly.

Other options that are presented in figure 8 are electricity production from biofuels using fuel cells and solar electricity production using photovoltaic (PV) cells. The use of fuel cells for electricity production is not yet mainstream. Solar electricity production with PV is nowadays standard technology. In PV cells, solar energy is directly used to produce electricity. Electricity efficiencies of commercially available PV modules are around 15%. The scale of PV power plants vary from very small (< 1 kW_e) to large (≈ 100 MW). Advantage of PV cells for electricity production is the possibility to integrate the cells with buildings and infrastructure.

Similar to electricity production based on heat, main disadvantages of these technologies are related to economic aspects. The majority of costs are made before actual electricity production starts while the price of electricity is not fixed but relates to prices of other electricity producing plants.

2.2.3 Energy storage technologies

When supply and demand of energy (electrical, heat and cold) do not coincide, storing surplus energy for future use can be beneficial. The storage capacity as well as the required storage time depends on the energy type (heat, cold or electricity). An example is given in figure 10 for the supply and demand of heat and cold for temperature control of buildings. Low temperatures are available in winter time whereas demand can be expected in summertime. Underground thermal energy storage (UTES) is a technique in which heat and/ or cold is stored in the subsurface. When needed, this heat and/ or cold is reclaimed and used for heating or cooling. With UTES it is possible to use the subsurface to buffer temporal fluctuations in heat/cold demand.

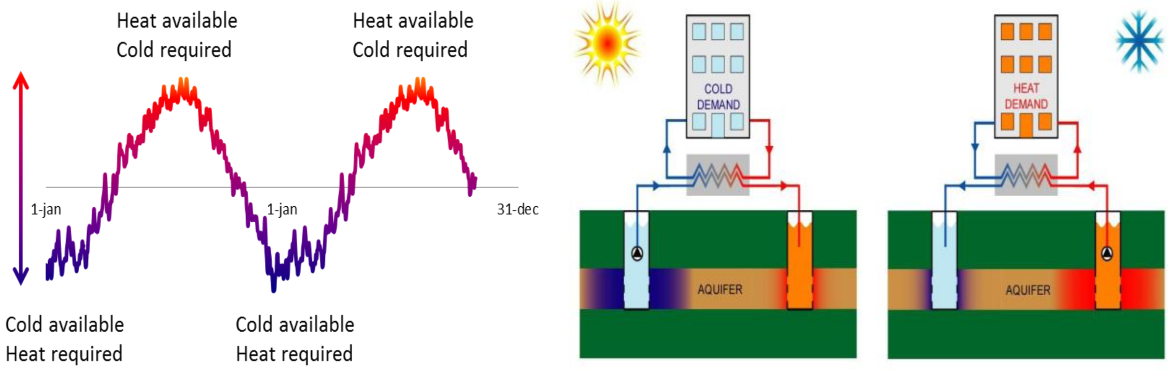


Figure 10: seasonal heat supply and demand (left) and seasonal storage of heat in ATES doublet system

UTES is being used as an alternative to conventional heating and cooling worldwide (Kun Sang Lee, 2010). Benefits of UTES are among others: 1) reduction in greenhouse gas emissions, 2) less dependence on fossil fuels and 3) savings on costs of heating and cooling.
A common division in UTES systems is between two types: 1) closed systems and 2) open systems. Closed systems, also known as borehole heat exchangers (BHE), consist of closed loops through the subsurface. Open systems are known as aquifer thermal energy storage systems (ATES). In open systems the groundwater itself is extracted and injected to exchange heat with the subsurface. Currently, ATES systems extract water between 20 and 200 meter below ground level (bgl).

ATES systems are usually divided into 1) recirculation systems, with different wells appointed for extraction and injection of groundwater, and 2) doublet systems, where flow direction is reversed every half year. Recirculation systems extract water of near constant temperature. The groundwater temperature in The Netherlands is around 11°C. Therefore, this water can be used directly for cooling purposes in summertime. During winter, the water can be used for preheating or higher temperature heating when a heat pump is used. The groundwater is injected back into the subsurface.

In doublet systems (sketched in figure 10), the direction of pumping can be reversed. Generally, this is done on a seasonal basis. In summertime groundwater is used for cooling, with as direct result a heating of the groundwater. This heated groundwater is injected into another well, creating a bubble of relatively warm water. During winter, the direction of pumping is reversed, so that this warm water can be used for (pre)heating. This process in turn cools the water, which is subsequently stored in the cold wells. This operation scheme results in the creation of one or more warm and cold wells. Since the surplus of heat from the summer and the surplus of cold in winter can be stored and used when needed, doublet systems have a higher efficiency than recirculation systems. The temperature in current ATES wells in the Netherlands is generally between 15 and 25 °C in the warm wells and around 7 °C in the cold wells (NVOE, 2009). At present high temperature storage systems are considered that can buffer heat at temperatures up to 90 °C. These temperatures make direct use of heat in industrial processes and spatial heating possible.

Within Europe, BHE systems are more widely used than ATES systems, because they can be installed at smaller scales (individual households) and are less dependent on soil type than ATES systems. However, ATES systems have generally a larger heat capacity per well (Kun Sang Lee, 2010) and can be more profitable when applied at larger scales (offices, groups of houses).

2.2.4 Present limitations and shortcomings individual technologies

The main limitation of the water and energy technology concepts that are described in this chapter is the focus on a specific service, either on the water system or the energy system. Developments to improve these technologies are also targeted on the performance of each individual technology. This sectorial approach overlooks possible synergies that can be found when integrating required services. Optimizing the demand side (required services) from a holistic perspective rather than optimizing the production side enables us to see opportunities that were otherwise missed.

Subsequent to this main limitation is the lack of possibilities to apply specific technologies within the existing site (area). Increasing environmental quality criteria require a constant "fixing" of technologies, leading to more and more complex systems. A continuous addition of technology steps lead to high costs, troubled responsibility, energy and money flows and lock-ins of technologies.

Another limitation of individual technologies, or maybe more the individual operators of technologies, buildings and plants, is the inefficient use of waste streams e.g. heat and water. In an area occupied by multiple users and property owners it is generally not in the interest of operators to market existing waste streams. Investments that are needed to exchange energy streams between different buildings and plants are regarded too high while demand, especially in brownfields, is uncertain. Furthermore plant operators give priority to their primary production process and are often not prepared to optimize an area's total water and energy consumption. On the other hand, consumers of energy and water are not willing to be dependent on a (single) non-public supplier. As a result, individual buildings consume fuels (or heat) and electricity while disposing waste heat. A schematic is given in figure 11.

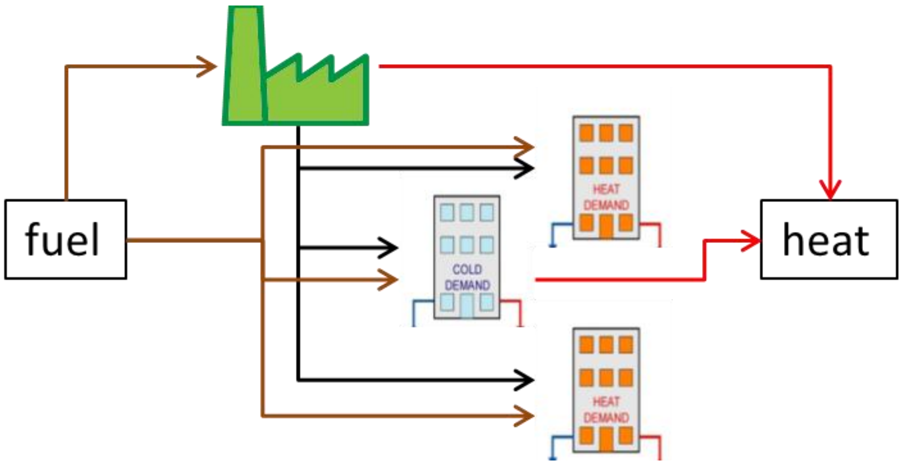


Figure 11: Schematic of current practices for supply of electricity (green building is electricity plant) and consumption of electricity and fuels for spatial heating. Waste heat is discarded and emitted to the environment.

2.3 Opportunities technology trains energy-water

As described in paragraph 2.2, many technologies exist to obtain required goods and services related to water and energy. These technologies are mostly connected as level 1 technology trains: simple technology train, or level 2 technology trains: integrated technology train to produce the required service from a variety of resources. These optimizations are common practice as the water and energy markets are already demand driven (providing required goods and services from a variety of resources for acceptable costs). Experiences applying level 3 energy-water technology trains are however limited. In the next sections some examples are given that are relevant to BF regeneration.

2.3.1 Synergies water oriented technologies with BF aspects

Synergies between water technologies pointed towards the water use cycle and other BF issues seem generally limited. However, water as energy carrier or as waste carrier provides some interesting combinations.

Energy
Heat from waste water can in principle be extracted from the sewage system and be used for low temperature heating. Whether this heat extraction is beneficial depends on the temperature that is required at the waste water treatment facility (is additional heating of waste water needed?). Synergy can be expected when anaerobic biological waste water treatment is combined with the production of biogas. This technology exists in many agricultural, foods, and paper related industries where organic contaminants are present in high concentrations and temperatures are moderate. Municipal waste water in Europe is not yet treated anaerobically while producing biogas; only the sludge is sometimes digested with biogas recovery.

Water technologies targeting groundwater or surface water contamination, especially geohydrological isolation, can provide heat and/or cold for low temperature heating systems and/or high temperature cooling systems before emitting the water to the receiving water system. A similar combination is possible for the discharge of cooling water for electric power plants.

Safety
Synergy between precipitation/flooding control and BF regeneration is more obvious. Although the problems to overcome are more spatial by origin, new combination of technologies may be needed to integrate the water system with the BF use. Construction of surface water in or nearby a BF has multiple positive effects. It provides for example a buffer for storm water discharge, it functions as a large solar thermal energy collector, it reduces the urban heat island effect, and it lowers infiltration of precipitated water thereby reducing the spreading of contaminants from soil to groundwater. Possibly a combination with heat/cold storage, soil-materials technology train, and soil-water technology train is attractive to assess.

2.3.2 Synergies energy oriented technologies with BF aspects

Synergies between energy technologies and other aspects are categorized in three groups.

Soil
Although the first step in any optimization of energy demand is the reduction of energy use, the production of waste heat streams cannot always be avoided. Waste heat, especially in the form of steam, can be used for rapid soil remediation of (semi-)volatile contaminants. Steam stripping of contaminants is generally an expensive remediation technique because of the energy costs and is not regarded as sustainable as the steam production involves the consumption of fossil fuels. When these aspects are not applicable, such is the case when steam is a waste stream of another production process, the use of this waste stream becomes beneficial. The main advantage is the rapidness of this remediation technique that enables the fast re-use of a BF. Furthermore there is no upper limit of contaminant concentrations that can be addressed and residual contaminants can be reduced to a minimum. Steam stripping can both be applied in-situ or ex-situ. Especially for the regeneration of BFs into residential use, combined with positive drivers (factors) of BF regeneration, this combination can be very beneficial. Depending on the continuity of the waste stream, the energy can be a service (space conditioning) of the new buildings.

Groundwater

Buffering of heat and cold in aquifers with an ATES system can be combined with (enhanced) natural attenuation of several groundwater contaminants. Although the effect of temperature on the biodegradation is limited (no net increase of temperature to prevent long term effects on geochemical processes), mixing of contaminants over a large area may be beneficial for the following reasons: reduction of concentration (below toxic levels) stimulate bio-degradation, increased mass transfer of substrate, nutrients and electron donors/acceptors to suppleted areas, dissolution of NAPLs, and distributing bacteria. Another advantage of this combination is the long term commitment of remediation. As ATES systems are designed for a period of several decades, also the mixing will continue for this period and, when some mass removal is possible, overall the quality of groundwater will improve. This combination however will not lead to a rapid removal of contaminants and a temporal, local increase of contaminant concentration can occur. Therefore social aspects (acceptance and legislative) must allow for this treatment.

Building materials

Optimization of costs and environmental quality for insulation of buildings and application of waste energy streams is proposed. The reuse of waste energy, especially heat, reduce the necessity of high insulation of building from a greenhouse gas emitting point of view. From an organizational point of view the dependency of heat consumers towards heat suppliers is however questionable.

2.3.3 Application of energy-water technology train in case studies

To test the principles of the energy-water technology train, a BF case is required where an energy demand, especially heat and cold, is expected and water (ground or surface) is available. The presence of contaminants in the aqueous phase is desired. Within the HOMBRE BF cases these conditions are present at the sites of Genua, Solec, and Terni. Of these BF cases Genua and Terni are the most interesting as information regarding the present and future use can be constructed,

The Terni case includes some very large buildings that are currently heated and cooled with traditional heating and cooling equipment. Application of ATES seems possible as the subsurface consists of sand and gravel. Furthermore the presence of a (small) river and contaminants makes it an ideal location to test the principles of ATES, heat/cold extraction from surface water combined with soil/aquifer remediation.

The Genua case is very interesting to test the valuation of ATES in a more urban setting. Depending on the geological characteristics ATES might be possible. More interesting is however the feasibility of ATES as a function of redevelopment plans. Depending on the development scenario (hospital or residential) heat and cold will be required at different intensities and amounts. Furthermore the location next to the river and the harbor provide additional heat or cold that can be used directly or stored in the aquifer. As information on aquifer contaminants is presently limited, the Genua BF will be very inspirational regarding the assessment off data requirement in relation to sustainable BF regeneration with respect to stakeholder ambition and participation.

The Solec case is less interesting for the energy water technology train as limited ideas are available to identify future energy requirements. However the geology of the site, combined with the presence of organic contaminants in the aquifer (originating from the creosote tanks) makes the site potentially attractive for a feasibility study.

Other HOMBRE cases were not considered.

3 Technology train building materials and soil

3.1 Introduction building materials and soil: specific BF problems

The regeneration of BFs usually requires the demolition of existing structures (buildings, industrial plants, tanks, etc.) and the excavation of soils and materials which may have a functional purpose (i.e. it is motivated by the need of the regeneration project) or environmental ones (i.e. it is motivated by the remediation project). These activities lead to the production (inputs) of soils, Construction and Demolition (C&D) waste and other excavated materials that must be dealt with. The management options depend on the quantity and quality of material flows produced and of materials required (outputs) by the regeneration strategy chosen for the specific BF case. This paragraph discusses the material flows typically produced in a Brownfield, analyzing separately those produced during the demolition activities, including basement and foundations, and those produced during the excavation of soil and other excavated materials. Furthermore, the different materials that are typically required in BF regeneration projects will be described making reference to the different regeneration scenarios that can be foreseen for the case studies of interest for WP4.

Different industrial activities may be potentially related to a Brownfield site, but only some of these activities produce solid (waste) materials which are attractive enough from the point of view of their reuse, in terms of quality and quantity of the materials produced. Table 1 lists some selected Brownfield site types and activities (EPA, 2005) that may have led to contamination over the operational history of these sites, and the contaminant groups typically associated with these activities.

Sections 3.1.1, 3.1.2 and 3.1.3 list and shortly describe the main input materials associated to a Brownfield regeneration process in terms of the activities which lead to the production of such materials and their classification according to the European Waste Catalogue.

Table 1: Typical contaminants found at Brownfield sites (adapted from EPA, 2005)

Site type	Site activities	Halogenated VOCs	Non halogenated VOCs	Halogenated SVOCs	Non halogenated SVOCs	Fuels	Metals and Metalloids	Explosive
Incinerator	An incinerator is an enclosed device that uses controlled flame combustion to thermally break down waste to an ash residue with a low content of combustible material. Incinerators may treat: municipal solid waste, sewage sludge or medical waste. Contamination may be associated with storage and handling of waste prior to incineration as well as disposal of the by-products of the combustion process			x			x	x
Municipal and industrial waste landfills	Landfills for industrial but also municipal solid waste may host many different types of materials such as oils, paints, solvents, corrosive cleaners, batteries, and gardening products that are likely to be contaminated with hazardous chemicals. Illegal dumping at landfills can also cause serious contamination. In addition, improper design may also lead to surface soil and groundwater contamination.	x	x	x	x	x	x	

Site type	Site activities	Halogenated VOCs	Non halogenated VOCs	Halogenated SVOCs	Non halogenated SVOCs	Fuels	Metals and Metalloids	Explosive
Mining	There are three general steps in the mining process: extraction of the mineral from the rock or matrix, beneficiation and processing. Beneficiation is the processing of extracted materials to clean or concentrate the product either for use as a final product or in preparation for further processing. Beneficiation may involve physical or chemical separation processes or both. Processing is conducted following beneficiation to further extract or refine the material and prepare it for specific uses. Processing may include a variety of operations such as smelting, refining, roasting and digesting. Chemical contamination at mining sites may result from acidic, metal-laden mine drainage. Spilled, leaked, or improperly disposed of petroleum, lubricants, and other industrial chemicals may also result in site contamination.	x				x	x	
Smelter operation	The primary use of smelting is to produce iron and steel from iron ore. Smelting is also used to extract copper and other base metals from raw ores. Contamination from smelting operations often takes the form of deposition of airborne metals, asbestos, and sulfur compounds in areas surrounding smelters. Contamination may also result from improper storage and disposal of raw ores or by-product slag.						x	

3.1.1 Inputs: Soils

Soil consists of a mixture of weathered minerals and varying amounts of organic matter. Soil properties vary from place to place with differences in composition, texture and other factors. Soil originated from a Brownfield site can be characterized by a certain extent and type of contamination as a result of the former industrial activities of the site itself.

Whenever the excavated soil is disposed of outside the BF site, a European Waste Catalogue (EWC) code must be assigned to it. As it will be also shown in the following of the document, the soil can be classified as one type of C&D waste, thus assuming a EWC code 17.05.04. Nevertheless, it is worth pointing out that soils from contaminated BFs may also be classified as 19.13.02 (or 19.13.01* if hazardous), that is as waste resulting from clean-up activities. The decision on the EWC code to apply may depend on the individual case and on the specific national regulatory approach.

3.1.2 Inputs: C&D waste

The construction sector generates a huge amount of waste in the different phases of the construction process, from the extraction of the raw materials, during the manufacture of materials, the construction process itself, its demolition and finally the disposal of the waste materials in landfills.
Furthermore, C&D waste can arise from a range of different origins, or site, as listed below (Symonds Group, 1999):

- "Demolish and clear sites": sites with structures or infrastructures to be demolished, but on which no new construction is planned in the short term;
- "Demolish, clear and build sites": sites with structures or infrastructures to be demolished prior to the erection of new ones;
- "Renovation sites": sites where the interior fittings (and possibly some structural elements as well) are to be removed and replaced;

- “Greenfield”: building sites, undeveloped sites on which new structures or infrastructures are to be erected;
- “Road build sites”: sites where a new road (or similar) is to be constructed on a green field or rubble free base;
- “Road refurbishment sites”: sites where an existing road (or similar) is to be resurfaced or substantially rebuilt.

Regarding its composition, the European Waste Catalogue classifies the C&D waste in nine sub-levels, as reported inTable 2

Table 2: European Waste Catalogue classification of C&D waste

Waste code	Waste description
17	**Construction and demolition waste (including excavated soil from contaminated sites)**
17 01	**Concrete, bricks, tiles and ceramics**
17 01 01	Concrete
17 01 02	Bricks
17 01 03	Tiles and ceramics
17 01 06*	Mixtures of, or separate fractions of concrete, bricks, tiles and ceramics containing dangerous substances
17 01 07	Mixture of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06
17 02	**Wood, glass and plastic**
17 02 01	Wood
17 02 02	Glass
17 02 03	Plastic
17 02 04*	Wood, glass and plastic waste containing or contaminated with hazardous substances
17	**Construction and demolition waste (including excavated soil from contaminated sites)**
17 03 01*	Bituminous mixtures containing coal tar
17 03 02	Bituminous mixtures containing other than those mentioned in 17 03 01
17 03 03*	Coal tar and tarred products
17 04	**Metals (including their alloys)**
17 04 01	Copper, bronze, brass
17 04 02	Aluminium
17 04 03	Lead
17 04 04	Zinc
17 04 05	Iron and steel
17 04 06	Tin
17 04 07	Mixed metals
17 04 09*	Metal waste contaminated with hazardous substances
17 04 10*	Cables containing crude oil, coal tar and other hazardous substances
17 04 11	Cables other than those mentioned in 17 04 10
17 05	**Soil (including excavated soil from contaminated sites), stones and dredging spoil**
17 05 03*	Soil and stones containing dangerous substances
17 05 04	Soil and stones other than those mentioned in 17 05 03
17 05 05*	Dredging spoil containing dangerous substances
17 05 06	Dredging spoil other than those mentioned 17 05 05
17 05 07*	Track ballast containing dangerous substances
17 05 08	Track ballast other than those mentioned in 17 05 07
17 06	**Insulation materials and asbestos-containing construction materials**
17 06 01*	Insulation materials containing asbestos
17 06 03*	Other insulation materials consisting of or containing dangerous substances

Waste code	Waste description
17 06 04	Insulation materials other than those mentioned in 17 06 01 and 17 06 03
17 06 05*	Construction materials containing asbestos
17 08	**Gypsum-based construction material**
17 08 01*	Gypsum-based construction materials contaminated with dangerous substances
17 08 02	Gypsum-based construction materials other than those mentioned in 17 08 01
17 09	**Other construction and demolition waste**
17 09 01*	Construction and demolition wastes containing mercury
17 09 02*	Construction and demolition wastes containing PCB (for example PCB-containing sealants, PCB-containing resin-based floorings, PCB-containing sealed glazing units, PCB-containing capacitors)
17 09 03*	Other construction and demolition wastes (including mixed wastes) containing dangerous substances
17 09 04	Mixed construction and demolition wastes other than those mentioned in 17 09 01, 17 09 02 and 17 09 03

3.1.3 Inputs: Other excavated materials

Along with contaminated soils and C&D wastes, Brownfield sites can present a wide variety of other solid materials, whose characteristics and contaminations mainly depend on the former use of the site. Table 3lists the European classification for the materials considered, specifying the type of activity leading to such solid material flows and the corresponding code of identification.

Table 3: European Waste Catalogue classification of other excavated materials

Waste code	Waste description
10	**Wastes from thermal processes**
10 01	**Wastes from power stations and other combustion plants**
10 01 02	Coal fly ash
10 02	**Wastes from the iron and steel industry**
10 02 01	Wastes from the processing of slag
10 02 02	Unprocessed slag
10 09	**Wastes from casting of ferrous pieces**
10 09 03	Furnace slag
19	**Wastes from waste management facilities, off-site waste water treatment plants and the preparation of water intended for human consumption and water for industrial use**
19 01	**Wastes from incineration or pyrolysis of waste**
19 01 12	Bottom ash and slag other than those mentioned in 19 01 11
19 01 13*	Fly ash containing dangerous substances

3.1.4 Materials required for the regeneration phase

Depending on the regeneration strategy chosen, part of the excavated solid material (inputs) could be possibly reused (eventually after specific treatment) for the redevelopment-regeneration of the site. The main output options where the materials produced as a result of Brownfield regeneration could be used are reported in Table 4.

Table 4: Output materials in the regeneration of Brownfield sites

Output	Description
Embankment or filling materials	An embankment refers to a volume of material that is placed and compacted for the purpose of raising the grade of a roadway (or railway) above the level of the existing surrounding ground surface or for creating an artificial barrier (e.g. sound barriers) A fill refers to a volume of material that is placed and compacted for

	the purpose of filling in a hole or depression
Aggregates	Aggregates are granular materials used in construction, used in a quantity of application such as, for example, production of concrete and road construction
Materials for concrete production (cement substitution)	Owing to their pozzolanic properties, some industrial by-products can be used as a replacement for some of the Portland cement content of concrete.
Hydraulically bound materials	Hydraulically bound materials are mixtures that set and harden by hydraulic reaction. They include Cement Stabilised Material (i.e. mixtures based on the fast setting and hardening characteristics of cement). They also include hydraulically bound mixtures based on slow setting and hardening binders made from industrial by-products such as pulverized fuel ash and blast furnace slag (AggRegain, http://aggregain.wrap.org.uk)

Thus, reuse options substantially fall into one or more of the categories specified in Table 4. For soils and other excavated materials, some recent proposed reuse options are listed in Table 5.

Regarding soil, it should be screened after excavation to remove coarse material. The coarse fraction could be directly reused on site after a washing pre-treatment (Scanferla et al., 2009). Conversely, the fine fraction can be treated for reuse by mixing the material with an hydraulic binder (e.g., cement, lime or other geo-polymers) in order to obtain an hydraulically bound mixture (HBM) with improved mechanical and environmental properties. Thus, the HBM produced could be possibly reused in road pavement layers (Hassan et al. 2005; Kolias et al., 2005), as an engineering fill in place of imported virgin materials (Dunster et al., 2005) or granulated and relocated in situ in the form of aggregates (Scanferla et al., 2009).

Regarding other excavated materials, there is a large utilization of Basic Oxygen Furnace and Electric Arc Furnace(BOF and EAF) slag as artificial aggregates in road construction and concrete production since these materials have shown good physical and mechanical properties, as well as environmental ones (Shen et al., 2009; Xue et al., 2006; Manso et al, 2006; Pasetto and Baldo, 2010).

Furthermore, also MSWI bottom ashes have some characteristics that make them suitable for reuse as aggregates for concrete production or road construction but a physical and/or chemical pre-treatment is often required (Forteza et al., 2004; Cheesemann et al., 2005; Sorlini et al., 2011). On the other hand, several authors have studied the possibility of recycling MSWI bottom and fly ash in cement manufacturing, since these materials show pozzolanic behaviour in the presence of cement or other binders, e.g. lime (Bertolini et al., 2004; Pan et al., 2008; Aubert et al., 2006). In both cases, a physical and/or chemical pre-treatment is often required. Sometimes, the reuse of industrial residues in construction applications relies on the manufacture of a HBM. As shown in the table, a HBM could allow the production of aggregates, generally for concrete manufacture (Cioffi et al., 2011).

Table 5: Reuse options for soils and other excavated materials

Input material	Output material	Proposed reuse	Reference
Contaminated sediments	HBM	Filling materials	Dunster et al., 2005
Contaminated soil (ø < 4 mm)	HBM	Aggregates for in situ relocation	Scanferla et al., 2009
Contaminated soil (ø > 4 mm)	Filling materials	Directly reused on site	Scanferla et al., 2009
Contaminated soil	HBM	Road base or sub base	Hassan et al., 2005
Non-contaminated soil	HBM	Pavement structure	Kolias et al., 2005
Steel slag (BOFs)	Aggregates	Aggregates in porous asphalt	Shen et al., 2009
Steel slag (BOFs)	Aggregates	Aggregates for road construction	Xue et al., 2006
Steel slag (EAFs)	Aggregates	Aggregates fro concrete	Manso et al., 2006
Steel slag (EAFs)	Aggregates	Aggregates for road construction	Pasetto and Baldo, 2010

Input material	Output material	Proposed reuse	Reference
MSWI bottom ash	Aggregates	Lightweight aggregates for concrete	Cheesemann et al., 2005
MSWI bottom ash	Aggregates	Road construction	Forteza et al., 2004
MSWI bottom ash	Aggregates	Aggregates for concrete	Sorlini et al., 2011
MSWI bottom ash	Materials for concrete production	Cement substitution	Bertolini et al., 2004
MSWI bottom ash and MSWI fly ash	Materials for concrete production	Cement substitution	Pan et al., 2007
MSWI fly ash	Materials for concrete production	Cement substitution	Bertolini et al., 2004
MSWI fly ash	Materials for concrete production	Cement substitution	Aubert et al., 2006
MSWI bottom ash	HBM	Aggregates for concrete	Cioffi et al., 2011

Moreover, the reuse of soils, C&D waste or industrial residues depends on physical, mechanical and chemical properties of the material to be reused. These properties, together with the main European Standards currently into force, are reviewed and discussed in Appendix 3.

3.2 Individual technologies currently used

This section provides an overview of the main techniques which could be possibly employed on soils and other excavated materials aimed to their reuse in the framework of regeneration project. Specifically, paragraphs 3.2.1 and 3.2.2 deal with the pre-treatments which could be required to enhance the performance of the technique, while some selected technologies aimed to materials' reuse are briefly outlined in paragraphs 3.2.3.

3.2.1 Physical/Mechanical pretreatments

When dealing with the treatment of waste materials in order to reuse them as useful products, a physical pre-treatment is often required in order to get a suitable particle size distribution and to separate the coarse fraction (typically the cleaner one) from the finest (usually the more polluted one). This can be achieved essentially by three types of processes, which are briefly described below.

<u>Sieving</u>
If the soil is excavated and then sieved into a coarse and fine fraction, most of the contaminants is assumed to be associated with the fine fraction. Furthermore with sieving operation it is possible to "adjust" the grain size distribution of the starting material if the subsequent treatment requires a certain particle size to be performed.

<u>Crushing</u>
Sometimes the starting material is not suitable to be directly re-used on site or further treated in a second step. In fact, coarse particle can negatively affect the material mixing and create problems for material handling. Moreover, some materials are too coarse to be reused as they are. In these cases, a crushing step may be added in order to reduce the average particle size dimensions.

<u>Washing</u>
In "physical" soil washing, differences between particle grain size, settling velocity, specific gravity, surface chemical behaviour and rarely magnetic properties are used to separate those particles which "host" the majority of the contamination from the bulk which are contaminant-depleted.
All soil washing processes use water. The water has a number of functions including to disaggregate the soil and to suspend the soil particles such that separation equipment performs effectively and efficiently;
In order the process to be effective, the "clean" fraction should be the bulk of the soil, which can then be used as fill material from excavation. The relatively small proportion of contaminated soil separated during washing can be more easily treated (at a considerably lesser volume than the original soil).

3.2.2 Chemical/Biological pretreatments

Land farming

Land farming is a bioremediation technology, which requires excavation and placement of contaminated soils, sediments, or sludge. Contaminated material is applied into lined beds and periodically turned over to aerate the waste. The waste, soil, climate, and biological activity interact dynamically as a system to degrade, transform, and immobilize waste constitutes.

Soil conditions are often controlled to optimize the rate of contaminant degradation. Conditions normally controlled include:

- moisture content (usually by irrigation or spraying).
- aeration (by tilling the soil with a predetermined frequency, the soil is mixed and aerated).
- pH (buffered near neutral pH by adding crushed limestone or agricultural lime).
- other amendments (e.g., nutrients, etc.).

Contaminated media is usually treated in layers that are up to 45 centimetres thick. When the desired level of treatment is achieved, the lift is removed and a new lift is constructed.

When treating a waste through a land farming process, a proper monitoring is required in order to prevent both on site and off site problems with ground water, surface water, air, or food chain contamination. Land farming has been proven most successful in treating petroleum hydrocarbons. Because lighter, more volatile hydrocarbons such as gasoline are treated very successfully by processes that rely on their volatility (i.e., soil vapour extraction), land farming is usually limited to heavier hydrocarbons. Factors that may limit the applicability and effectiveness of the process include:

- conditions affecting biological degradation of contaminants (e.g., temperature, rain fall) are largely uncontrolled, which increases the length of time to complete remediation.
- inorganic contaminants will not be biodegraded.
- volatile contaminants, such as solvents, must be pre-treated because they would volatilize into the atmosphere, causing air pollution.
- dust control is an important consideration, especially during tilling and other material handling operations.
- runoff collection facilities must be constructed and monitored.
- topography, erosion, climate, soil stratigraphy, and permeability of the soil at the site must be evaluated to determine the optimum design of facility.

Biopiles

Biopile treatment is a technology in which excavated soils are mixed with soil amendments and placed on a treatment area that includes leachate collection systems and some form of aeration. It is used to reduce concentrations of petroleum constituents in excavated soils through the use of biodegradation. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation. The treatment area will be generally contained with an impermeable liner to minimize the risk of contaminants leaching into uncontaminated soil. The drainage itself may be treated in a bioreactor. Biopile treatment can be successfully applied to the treatment of non-halogenated VOCs and fuel hydrocarbons. Halogenated VOCs, SVOCs, and pesticides also can be treated, but the process effectiveness will vary and may be applicable only to some compounds within these contaminant groups.

Factors that may limit the applicability and effectiveness of the process include:

- treatability testing should be conducted to determine the biodegradability of contaminants and appropriate oxygenation and nutrient loading rates.
- static treatment processes may result in less uniform treatment than processes that involve periodic mixing.

Composting

Composting is a controlled biological process by which organic contaminants (e.g., PAH's) are converted by microorganisms (under aerobic and anaerobic conditions) to stabilized by-products. Typically, a temperature between 54 and 65 °C must be maintained to properly compost soil contaminated with hazardous organic contaminants. The treatment further involves an increasing in temperature, produced by microorganisms during the degradation of the organic material in the waste. Soils are excavated and mixed with bulking agents and organic amendments, e.g. wood chips, to enhance the porosity of the mixture to be decomposed. Maximum degradation efficiency is achieved through maintaining oxygenation and irrigation as necessary. The composting process may be applied to soils and lagoon sediments contaminated with biodegradable organic compounds.

The following factors may limit the applicability and effectiveness of the process:

- the excavation of contaminated soils may cause the uncontrolled release of VOCs.
- although levels of metals may be reduced via dilution, heavy metals are not treated by this method. Also high levels of heavy metals can be toxic to the microorganisms.

Slurry phase biological treatment

Slurry phase biological treatment involves the controlled treatment of excavated soil in a bioreactor. The excavated soil is first processed to physically separate stones and rubble. The soil is then mixed with water to a predetermined concentration depending on the concentration of the contaminants, the rate of biodegradation, and the physical nature of the soils. Some processes pre-wash the soil to concentrate the contaminants. The solids are maintained in suspension in a reactor vessel and mixed with nutrients and oxygen. Microorganisms also may be added if a suitable population is not present. When biodegradation is complete, the soil slurry is dewatered. Bioremediation techniques have been successfully used to remediate soils, sludge, and sediments contaminated by petroleum hydrocarbons, petrochemicals, solvents, pesticides, wood preservatives, and other organic chemicals. Bioreactors are favored over in situ biological techniques for heterogeneous soils, low permeability soils, areas where underlying ground water would be difficult to capture, or when faster treatment times are required.

Factors that may limit the applicability and effectiveness of the slurry-phase biological treatment process include:

- non homogeneous soils and clayey soils can create materials handling problems.
- dewatering soil fines after treatment can be expensive.
- an acceptable method for disposing of non-recycled wastewaters is required.

Solvent extraction

Solvent extraction is a common form of chemical extraction using organic solvent as the extractant. Traces of solvent may remain within the treated soil matrix, so the toxicity of the solvent is an important consideration.

Solvent extraction has been shown to be effective in treating sediments, sludge, and soils containing primarily organic contaminants such as PCB's, VOCs, halogenated solvents, and petroleum wastes.

Factors that may limit the applicability and effectiveness of the process include:

- some soil types and moisture content levels will adversely impact process performance.
- higher clay content may reduce extraction efficiency and require longer contact times.
- traces of solvent may remain in the treated solids;
- solvent extraction is generally least effective on very high molecular weight organic and very hydrophilic substances.

Chemical reduction/oxidation

Reduction/oxidation (Redox) reactions chemically convert hazardous contaminants to non-hazardous or less toxic compounds that are more stable and less mobile. Redox reactions involve the transfer of electrons from one compound to another. Specifically, one reactant is oxidized (loses electrons) and one is reduced (gains electrons). Some of the oxidizing agents most commonly used for the treatment of hazardous contaminants are ozone and hydrogen peroxide.

The target contaminant group for chemical redox is inorganics.

Factors that may limit the applicability and effectiveness of the process include:

- incomplete oxidation or formation of intermediate contaminants may occur depending upon the contaminants and oxidizing agents used.
- the process is not cost-effective for high contaminant concentrations because of the large amounts of oxidizing agent required.

Chemical soil washing

With "chemical" soil washing, soil particles are cleaned by selectively transferring the contaminants on the soil into solution. This is achieved by mixing the soil with aqueous solutions of acids, alkalis, other solvents and surfactants. The resulting cleaned particles are then separated from the resulting aqueous solution. This solution is then treated to remove the contaminants (e.g. by sorption on activated carbon or ion exchange).

This technique can result in the contamination being destroyed and for some contaminants; the disadvantage of the technique is that it requires the input of a chemical reagent which can be both expensive and hazardous.

3.2.3 Treatment aimed at reuse

Solidification/Stabilization (S/S)
Stabilization/solidification is a relatively simple civil-engineering-based remediation technique involving the controlled addition and mixing of binders with contaminated soils to form a new solid, ranging from a granular solid to a monolith (Angel et al., 2004). Within this solid, contaminants are rendered immobile and become virtually non-leachable. Although not removed or destroyed, contaminants are prevented from being available into the environment.

S/S is defined as a remediation technology that relies on the reaction between a binder and soil to reduce the mobility of contaminants (Environment AgencyUK, 2004). There are two separate mechanisms:
Solidification refers to processes that encapsulate a waste to form a solid material and to restrict contaminant migration by decreasing the surface area exposed to leaching and/or by coating the waste with low-permeability materials.
Stabilization refers to processes that involve chemical reactions that reduce the leach ability of a waste. Stabilization chemically immobilizes hazardous materials or reduces their solubility through a chemical reaction.
Other similar definitions for S/S can be found in publications by U.S.EPA (EPA, 2000).
The broad objective of S/S technology is to contain a waste and prevent it from entering the environment. In practice this broad objective may be realized by several mechanisms which lead to factors important in assessing S/S technology. These are (Wiles, 1987):

- produce a solid,
- improve handling characteristics of the waste,
- decrease the surface area across which the transport of the contaminant may occur
- limit the solubility of the contaminant when exposed to leaching fluids.

S/S treatment methodologies have been widely used over the past three decades, particularly in the United States where it already was an established treatment methodology more than ten years ago (EPA, 2000). Regarding the type of contamination, S/S has been used predominantly for the treatment of metals and metalloids, with other uses being relatively minor (EPA, 2007).
Nowadays, S/S is also an increasingly technology for Brownfield regeneration since treated materials can be also reused within the site or in the surrounding area, improving site conditions and eliminating the need for virgin raw materials (EPA, 2009). This goal can be achieved also by combining S/S with other technologies, e.g. granulation (Scanferla et al., 2009; Cioffi et al., 2011), carbonation (Antemir et al., 2010), granulation and carbonation (Melton et al., 2008; Gunning et al., 2009).

Since the applicability of S/S processes to soils and waste materials depends on several variables (among other, type and characteristics of the material to be treated; type and extent of contamination), specifying criteria for applicability of S/S is difficult without the availability of site-specific data and of the results of treatability tests.

Nevertheless, some “applicability indication” was extrapolated from lab-scale experimental data and data collected from field-scale case studies. As a result, a list of the main properties of the materials to be treated, affecting the applicability and the expected performance of S/S, are reported in Table 6. Preliminary values of these properties allowing for applicability of S/S treatment are also proposed in the same table, although it should be noted that other works have reported the effectiveness of this type of treatment for different conditions than those discussed below. For example, Chen and co-workers (Chen et al., 2009) have proposed a threshold value of 74 µm, since it was found that smaller particles could delay setting and hardening of the binder; but other S/S treatments have been successfully applied also on materials with a high clay content, which means on particle with ø < 2 µm (Mater et al., 2006; Al-Ansary and Al-Tabbaa, 2007). Regarding pH, according to Stegemann and Zhou (Stegemann and Zhou, 2009), wastes for S/S should have a neutral to alkaline pH but acidic matrixes can also be treated by using lime as binding agent (Dermatas and Meng, 2003; Garcia et al., 2004; Mater et al., 2006).

As already said, solidification/stabilization is a treatment suitable for immobilizing inorganic hazardous constituents. Conversely, the application to organic compounds has always been controversial. It was reported that organic compounds tend to have a detrimental effect on the properties of cementitious materials and they may be leached out after the curing process (Sora et al., 2002; Karamalidis and Voudrias., 2007; Antemir et al., 2010.). However, the efficiency of S/S treatment of organic contaminants may be improved using adsorbents for the organic components (Gitipour et al., 1997; Rho et al., 2001; Cioffi et al., 2001; Sora et al., 2005). Also when using adsorbents to improve the efficiency of the process, relatively low concentrations of organic compounds can be treated, as reported by EPA (EPA, 2009). Nevertheless, it should be pointed out that higher concentrations of PAHs were treated by other researchers (Mulder et al., 2001; Mater et al., 2006).

Table 6: Main properties to be considered for S/S processes

Main properties	Applicability conditions	Reference
Organic contaminants concentration	PCB < 500 ppm PCP < 200 ppm PAH < 30 ppm Dioxins < 50 ppm	EPA, 2009; Environment AgencyUK, 2004
Particle size	ø > 74 µm. ø < 4 mm.	Chen et al., 2009; Scanferla et al., 2009
Carbon content	TOC < 1%	Stegemann and Zhou, 2009
pH	pH > 7; pH < 12	Stegemann and Zhou, 2009
Chloride concentration	< 5%	Stegemann and Zhou, 2009; Al-Ansary and Al-Tabbaa, 2007; Leonard and Stegemann, 2010.

Accelerated carbonation

Carbonation is a natural occurring process which involves the reaction between atmospheric CO_2 and alkaline materials. When CO_2 reacts with metal oxides (indicated here as MO, where M is a divalent metal, e.g., calcium, magnesium, or iron) the corresponding carbonate is formed and heat is released according to the following chemical reaction (IPCC, 2005):

$$MO + CO_2 \rightarrow MCO_3 + heat \qquad 1)$$

Natural carbonation reactions are generally quite slow and became significant in the long term. This reaction can be accelerated by contacting the alkaline material with a gas stream concentrated in CO_2 at specific operating conditions (e.g.: temperature, CO_2 partial pressure and liquid to solid ratio).
Apart from accelerated carbonation of primary alkaline earth minerals (in particular Mg and Ca silicates, such as olivine and serpentine), which is especially investigated as a CO_2 capture and storage (CCS) option, the accelerated carbonation of alkaline waste residues has been taken into consideration in recent years for several reasons. These materials are often associated with CO_2 point source emissions and tend to be chemically more unstable than geologically derived minerals and therefore require a lower degree of pre-treatment and less energy intensive operating conditions. Furthermore, carbonation processes have significant effects on alkaline materials, which include specifically: CO_2 uptake in a solid and thermodynamically stable form, pH decrease and modifications of the leaching behaviour of the material, besides variations of some of the physical, mineralogical and mechanical properties of the treated material.

Many waste materials are reactive with carbon dioxide, particularly those derived from industrial thermal processes, such as incineration ashes (Baciocchi et al., 2006a,b; Arickx et al., 2006) and steel slags (Baciocchi et al., 2010). Other materials investigated include biomass ash, cement kiln dusts, paper wastewater sludge incineration ash, pulverized fuel ash, sewage sludge ash, wood ash (Gunning et al., 2009; Gunning et al., 2010) and in general waste containing cementitious phases (Fernandez Bertos et al., 2004). This process has been also adopted in combination with other techniques (such as stabilization/solidification and/or granulation) as a remediation strategy for contaminated soils and sediments (Melton et al., 2008; Antemir et al., 2010).

Thermal treatment – Vitrification

Vitrification is the process of converting materials into a glass or glassy substance, through a thermal process (EPA, 1992). Vitrification may destroy organic contaminants via pyrolysis or combustion.

As a stabilization process, vitrification may immobilize inorganics by incorporating them into the glass structure or by encapsulating them into the product glass. Many contaminated materials contain adequate quantities of the raw ingredients needed for forming glass. When such materials are heated, the ingredients melt together and actually form the glass in which the contaminants are immobilized. Because not all the contaminated materials contain proper ratio of the materials for the formation of a glass, additives may be required for some materials to address this insufficiency.

Vitrification is a well-established technology in the treatment of contaminated soils and other solid materials. Particularly, a variety of applications on MSWI residues for a safe waste management can be found in the scientific literature (Haugsten and Gustavson, 2000; Park and Heo, 2002). Furthermore, the obtained glassy material is substantially inert towards most chemical and biological agents, thus the possibility of reusing the vitrified products in construction applications (e.g. roads, pavements, embankments) has been also considered, (Sakai and Hiraoka, 2000; Wey et al., 2006; Sørensen et al., 2001).

A combination of technologies (e.g., vitrification and granulation) has also been recently proposed in order to produce aggregates to be reused in construction applications (Cheesemann et al., 2005; Cheesemann and Virdi, 2005).

Granulation

Granulation is the process of agglomerating particles together into larger, semi-permanent aggregates. In wet granulation processes, this is performed by spraying a liquid binder onto the particles as they are agitated in a tumbling drum, fluidized bed, high shear mixer or similar device. The liquid binds the particles together by a combination of capillary pressure, surface tension and viscous forces until solid bonds are formed by subsequent drying. Some advantages of agglomerated materials include improved flow properties, reduced dustiness, increased bulk density and the co-mixing of particles which might otherwise segregate. Because of these features, granulation unit operations occur in a wide range of industries including agricultural products, pharmaceuticals, detergents and food stuffs. (Iveson et al., 2001).

In the last few years, granulation process has been extended to waste materials treatment in order to obtain granules with suitable properties which could permit to reuse them for construction purposes. For this kind of applications a combination of technologies is often required in order to obtain suitable physical, mechanical and environmental characteristics. The “technology trains” recently investigated include granulation and stabilization/solidification (Scanferla et al., 2009; Cioffi et al., 2011), granulation and vitrification (Cheesemann et al., 2005; Cheesemann and Virdi, 2005), granulation, stabilization/solidification and carbonation (Melton et al., 2008; Gunning et al., 2009).

Regarding the applicability of the process, particle size is the most relevant parameter to be considered. Essentially the process needs particles with ø < 125 µm to be performed (Medici et al., 2000; Cioffi et al., 2011). When the starting particles dimensions are not suitable for treatment, physical pre-treatment can be employed in order to get a powder (Cioffi et al., 2011).
Furthermore, granulation process has also been applied to coarser particles (ø < 4 mm) by using cement as binder in order to produce aggregates (Scanferla et al., 2009).

3.2.4 Techniques aimed at the reuse of C&D waste

In the construction sector the composition of demolition waste is generally characterized by a majority fraction of rubble bricks, tiles, ceramics, concrete, stony sandy and aggregate materials whose sound and sustainable management is of special concern and attention. Others materials include fractions in small quantities to be sorted and delivered to authorized managers for proper environmental treatment like non inert waste, dangerous asbestos, mineral fibers, solvents, certain paints, resins and plastics. The basic principle of C&D Waste treatment plant is the separation and release of the components of the all-one and group evenly in order to re-use, recycling, recover or dispose in a controlled manner. A recycling plant has a structure similar to a plant for processing natural raw materials with the same facilities and equipment, namely, crushers, screens and conveyor mechanisms. Its complexity depends on the required degree of processing of the C&DW´s. That is the quality of the waste received at the plant and the requires end use of recycled material.

A necessary condition for the recycling of construction waste is a careful separation, because the efficiency of recycling will be influenced by the degree of mixing of the waste at its source. Waste from new construction and restorations were selected either in the place of production or in a special treatment. The separation of the various categories of materials in these cases is quite simple. The ease or validity in the recycling of construction waste materials depends on separating the site and in coordination with the construction or demolition, to prevent mixing of materials and contamination of recyclable materials. If there is no obligation requirement of separation its only destination is the elimination in the landfill. If there is separation requirement it is feasible to book the work spaces in which to store the waste types for recycling.The following waste will be reused and should be separated to be recycled: paper, plastics, glass, steel and wood.

All other materials are eliminated in landfills or they will be able to take part in the restoration of degraded sites, refurbishment works or fill. The work that involves separation of waste may seem a process that is more expensive than without this separation, due to the increased time spent on its development. However, the cost savings increase, because there is a higher quality of waste at source and eliminates the selection needed in the recycling plant. It also saves transportation costs and rates of release.

Source separation

Among the first difficulties of recycling is the heterogeneity of the starting materials. The more homogeneous the waste streams are in the source, the more the produced recycled materials will be reused. Today, the availability of technologies such as for the source separation is very limited in many countries. The systematic approach to address this aspect is mainly a matter of organization. Selective demolition is the first step which greatly favors the possibility of recycling the materials contained in the waste of construction and demolition, because it provides more and better market outlets for recycled materials and because it extends the possibilities of recycling more of those. It is an 'optional' activity. The one which has the greatest influence on the extent to which materials are re-used and/or recycled, is by common consent, selective separation at source.

After the structure has been demolished it is normally possible to remove further steel (or possibly wooden) beams which were part of the basic structure (and therefore could not be removed previously). By using heavy duty mechanical 'scissor' crushers to break open reinforced concrete members, some of the steel reinforcing bars can also be removed. Some insulation materials which were inside walls can also be removed by hand (or, possibly more accurately, by non-automated processes). Limitations of the selective separation of waste are the following:

- The intrinsic properties of the generation of waste mixed state or group submitting the form.
- The physical space available in the works, depending on the type of work involved, this may be limited or extensive.
- The culture or tradition of construction personnel;
- Participation in the same period of different subcontractors to perform work;
- The pace of implementation of urgent works;
- The environmental policy.

C&D Waste processing

Recycling in centralized plants is very common in the European Union just like the use of mobile plants for the production of secondary aggregates. The choice whether crushing and sorting should be done on- or off-site is complex, and depends on many factors including:

- The quality of aggregate required on the demolition site itself;
- The space and time available on the demolition site;
- The haul distances between the site, the nearest available fixed processing site and other treatment and disposal sites.

In practice, the answer will tend to reflect national and local practice and licensing (including land use planning and environmental controls), and market. Once the rubble goes off-site for crushing, it becomes less likely that it will be re-used on the original site. Annex 1 summarises the key factors associated with a choice between on- and off-site crushing and sorting facilities.

Technology concepts that are used for recycling C&D Waste are in principle independent of the choice for on- or off site treatment. Figure 12 shows two separate diagrams for the process of C&D Waste recycling based on either mixed wastes or the fraction of bricks, tile sand concrete. The overall process consist of different stages and unit operations. In both cases it is assumed that after the demolition a selective separation has been practiced and all hazardous fractions present in the building under demolition assessed. In all cases the material entering the plant must be free of dangerous substances.

Construction and Demolition Waste" is generally manually screened before it passes a sieve and a magnetic separator. This is followed by manual separation to eliminate the plastic, wood, wastepaper and other non-metallic the "Mixture of Construction and Demolition Waste" is then subjected to crushing and magnetic separation prior to magnetic separator passed through the air and removes the light fraction(small pieces of paper, plastic escaping from the first classification). Some recycling centers also have wood-processing plants and composting.

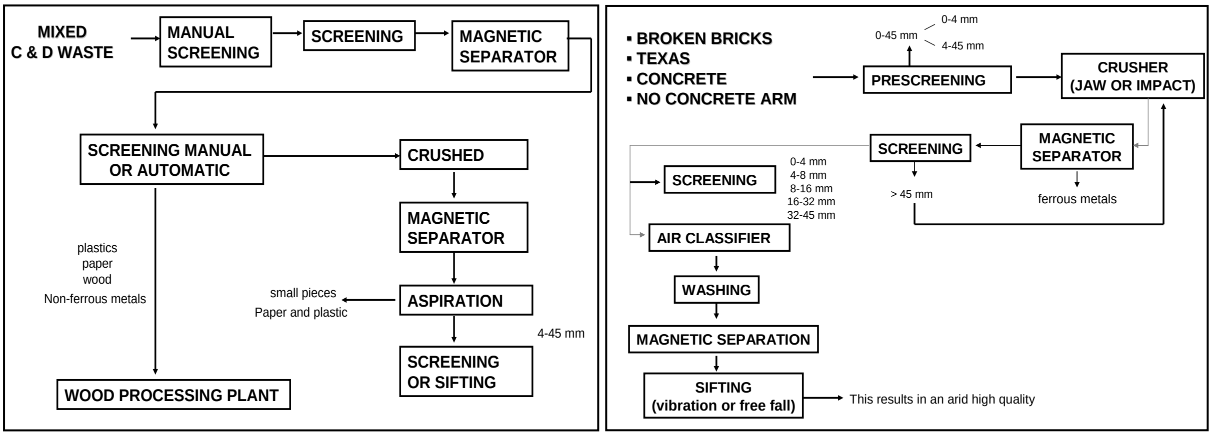


Figure 12: Process of inert C&D waste management for mixed, heterogeneous waste streams (left) and homogeneous waste streams (right).

The operation units that can be performed at the treatment plant are described from least to greatest complexity as follows.

Pre-selection or clearing:
Is the separation of recoverable materials and other voluminous fractions. Combination can be performed manually or mechanically.

Rifling classification manual:
It is a simple operation which is usually placed at the beginning of the process, or in other downstream interleaved to facilitate product recovery or disposal of recoverable or elimination of certain elements that hinder the next step. To make the stretch, marks are typically installed conveyors broadband, flat and low-speed rollers, mounted on an elevated structure on the ground, with aisles on both sides of which have operators who choose to separate materials (metals, wood, plastic, etc.) and placed in mailboxes. At the bottom are placed the different containers that collect the materials selected in the striatum.

Sizing and grading:
The granulometric classification is done with mechanical equipment screening, such as the following:
▪ Grills incline ▪ Rotary screens ▪ Pre-screeners vibrant or "grizzly" ▪ Vibrating screen

Magnetic separation:
For the magnetic separation recoverable iron elements are removed in order to facilitate the next process step. They are over band type machines and behind all grinding must be a magnetic separation to remove metallic materials released for the following reasons:

The ferrous materials are recoverable. In fact, the steel reinforcement of concrete is a product that sells easily on-site recycling of construction and demolition waste.

Recycled aggregates obtained from construction and demolition waste must have the minimum amount of metal, since the greater their presence in the arid, the lower quality of recycling. Furthermore, the presence of ferrous materials in the secondary crushing stage significantly reduces the life of the machinery due to excessive abrasion.

Grinding or crushing operations:
They reduce the size of the debris and at the same time release of materials, as in the case of iron reinforced concrete. We distinguish between primary and secondary crushing as the fed and grain size of the required product. Basic equipment is:

- The roller grinder, horizontal flow reduces the size according to the proximity of the base plate feeder that supplies material. It has the advantage of being situated at ground level or a minimum incline ramp, which makes it very advantageous for crushing concrete beams of great length.
- Jaw crushers, horizontal or vertical flow. They are very robust construction, with large inlet opening for bulky items and operational reliability. The drawback of these machines is that they produce materials with low cubical, and its advantage is that they suffer less wear even with highly abrasive materials.
- Impact crushers, have a rotor with bar throwing the material against the internal walls coated with anti-abrasive steel plates, reducing its size in a very high relative to food. The cubical end product makes them indispensable in the secondary crushing.
- Portable Cone Crusher

Pneumatics classification:
It uses air classification to remove the fragments of the lighter elements, such as papers and plastics that contaminate recycled material. The following are several air separation systems:

The Vertical suction, consisting of a feeder deposits the screening material on a cylindrical tank connected to a ventilator. The fan creates a vacuum that sucks the light at the top.

Pneumatic Screen is an inclined through a sieve through which air is blown from the bottom. The lightweight material is ejected to the side while the heavy continues its advance.

Wind Tunnel double effect, air flows through lightweight materials are moved to the output conveyor.

In the future other systems will apply more complex shredding and separation, as the selective combination treatment or wet boxes pulse or density separators. Through these processes recycled products can be obtained with most demanding specifications. Their performance and cost of production makes them impractical today, mainly due to the low selling price of recycled materials.

3.2.5 Present limitations and shortcomings individual technologies

The current approach in BF regeneration in most EU countries (Business As Usual – BAS) is a sequential approach. Buildings are first dismantled followed by removal of C&D waste off site and land filled. The reuse of these materials in the site or eventually outside the site for beneficial use is rarely adopted, although is some EU countries, such as the Netherlands, selected C&D wastes (bricks, concrete) are reused mostly off-site. Contaminated soils are mostly excavated and also transported off site where these soils are treated or land filled. This practice has many motivations which are also related to the national legislative frameworks applied for waste and soil management. In fact, the management of excavated soils, waste and other materials usually occurs without knowing the goal of the regeneration project, but only as a result of the need of solving the issues related to the soil contamination and to the presence of wastes in the site; this makes it difficult to have a recycle option available when the waste and soils have to be managed. Secondly, the current regulatory framework often limits the possibility of reusing soil and waste materials in the site and, even when this is made possible, quite strict environmental requirements may apply, that can possibly hinder or delay the reuse option. Finally, it is worth pointing out that the current drivers to BF regeneration projects, as far as the management of soil and waste is concerned, are very often simply the time of execution and the best guarantee of delivering the remediation goal and rarely include other drivers.

3.3 Opportunities technology trains building materials-soil

As already pointed out in the introduction to WP4, the HOMBRE project, and specifically WP4, pursues a paradigm shift, where the environmental problems associated to a BF may become an opportunity for the site itself and the neighborhood. For example in the case of C&D waste materials, these technologies can consist in the techniques capable of generating high quality aggregates as an output product. National legislation however can limit the application of these products off-site.

The review of individual technologies, reported in Chapter 2, has shown that these can provide a solution to specific environmental issues, but they cannot provide a comprehensive holistic solution to the BF site regeneration problem, as outlined above. As a consequence, there is the need of providing a more effective answer, through the development of technology trains, i.e. a combination of technologies, each of which cannot deliver a required product or service by itself, but that properly combined may meet this goal. As shown in the flowchart reported in Figure 13, which makes reference to excavated soil and/or residues available at the BF site as a result of the regeneration project, Technology Trains provide the bridge between resources available at the site and the required product or service for broader use.

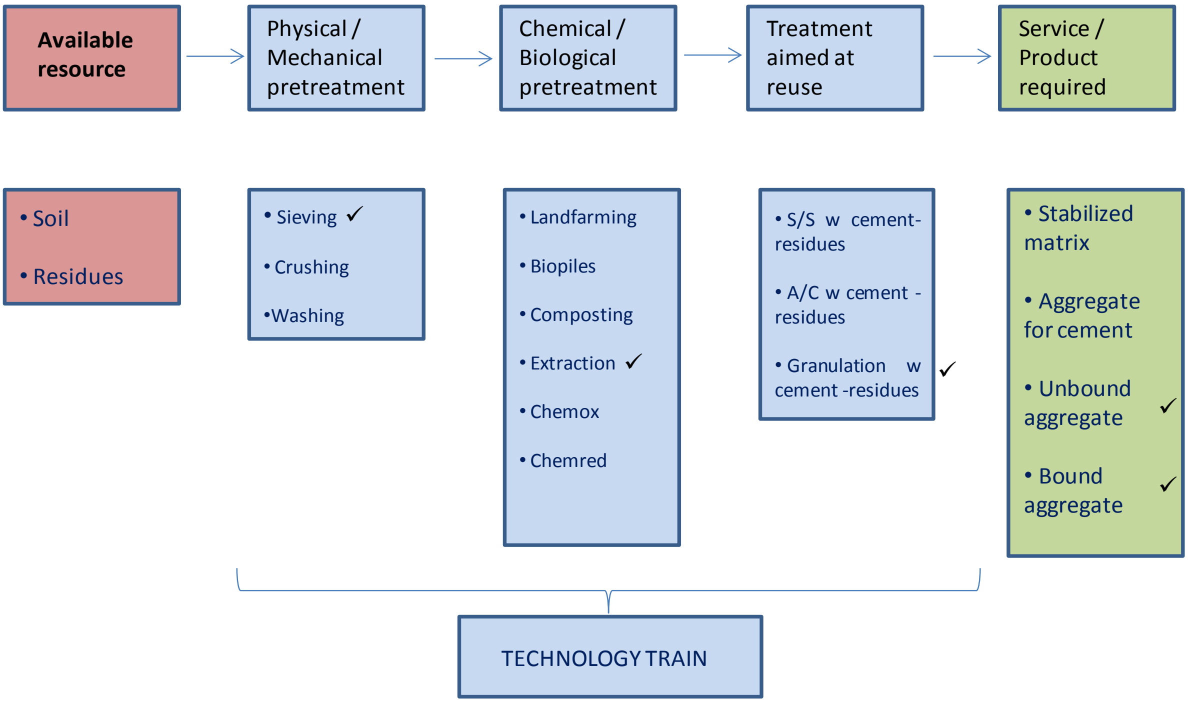


Figure 13: General scheme of technology train 2 (ticks refer to discussion in section 3.4)

3.3.1 Preliminary identification of technological/environmental indicators of success

As different combinations of the individual technologies, i.e. more than one technology train, can be possibly selected, a rationale for the choice of the more suitable technology train can be based on the use of proper indicator(s) of success. To this aim, two sets of indicators will be used within the HOMBRE project.

A first set includes those indicators of success that have to be fulfilled for achieving an effective regeneration process. As an example:

- unacceptable risks from contaminant presence have been removed in such a way that soil quality is compatible with the planned use of the site;
- project's planned budget has been respected;
- deadlines for the execution of the project have been respected;
- stakeholders expectations have been responded satisfactory;
- present waste material on the site has been properly managed and does not hinder further planned developments on the site (independently from the final destination of the waste: landfill, re-use, valorization…);
- in general stakeholders objectives have been reached.

In the HOMBRE approach this set of indicators of success will be coupled with a second set that is introduced in order to assess the sustainability of the regeneration option. As an example:

- the environmental footprint of the project has been minimized;
- land and ecosystems impact have been minimized;
- energy use and carbon emissions have been minimized;
- water use and impacts have been minimized;
- material consumption and waste generation have been minimized;

- air emissions have been minimized;
- carbon emissions have been minimized.

The two sets of indicators will be properly coupled and integrated to develop a suitable metrics for assessing the regeneration technology trains, leading to the selection of the most suitable one.

3.3.2 Operating windows: definitions and goals (linking the wagons)

In the HOMBRE vision, technology train provide a quality shift in regeneration of Brownfields as they aim to provide simultaneously site specific solutions to identified priorities (e.g. risk management, aesthetic issue, waste problem) and opportunities for third parties to make the best of “resources” and services so far not considered (benefits and though value). As shown in Figure 13, with reference to the soil/waste case, the link between the site-specific priority (for instance the need of removing a given volume of soil) and the service needed (for instance an aggregate for road construction) can be provided by matching individual technologies with another one, i.e. by assembling a technology train. This matching may be performed once that the operational limits of each technology with respect to another one are known, that is once that the range of application of each individual technology is known *a-priori*. In the HOMBRE approach this means to define the “Operating Window” of each individual technology.

3.3.3 Application of building materials-soil technology train to case studies

Let us consider the case study of Vercelli, where we have contaminated soils/wastes. The BAS approach is based on dig and dump; no connection to the redevelopment of the site is found in the current project. This results in high remediation costs that have so far stopped any resolution of the problem.

With the HOMBRE approach, we see at least two services:

- landscaping of the site + new road/paved areas construction
- energy (related to the incineration plant).

Therefore, we may consider a process based on granulation/carbonation where

- a construction material is obtained for landscaping/road construction
- CO_2 from the incinerator is used

Technology train(s) will have to be built by selecting the individual technologies needed and properly coupling them. The different technology trains and the BAS option shall be assessed in terms of the indicators of success as outlined above.

Making reference to the general scheme of Technology Train 2, the soils and residues collected at the site of Vercelli will have possibly to be treated using the following train:

- Physical pretreatment: sieving aimed to separate the coarse fraction (typically not contaminated) from the fine fraction (typically contaminated);
- Chemical/Biological pretreatment of the fine fraction: if the presence of organic compounds exceeds the operating window of the “treatments aimed at reuse”, their removal shall be obtained through a process to be selected based on the contaminants type and concentration (possibly extraction with a proper solvent);
- Treatment aimed at reuse: given the soil/residues properties, a granulation process eventually coupled to carbonation (using CO_2 from the plant) could be tested in order to get a material suitable to be used as unbound or eventually bound aggregate.

In the Vercelli case, it is expected that the adoption of the technology train proposed within HOMBRE will lead to a reduction in abiotic resource use, land use, greenhouse gases emissions and possibly in costs, with respect to the BAS option. Clearly, the products we get shall comply with physical/mechanical and environmental constraints, the former ones quite clearly defined in international standard, whereas the environmental constraints differ greatly depending on the national approaches.

4 Technology train soil and water

4.1 Introduction soil and water: specific BF problems

BF problems that are associated with the soil-water system can relate to soil and (ground-)water quality (contamination), and groundwater quantity (flooding, draught). The assessment whether problems exist or arise during and after BF regeneration depends on the available resources (soil and (ground)water quality and quantity) and the required services at some time (soil and (ground)water usage including functions such as carrying capacity for buildings, ecosystems and humans, and aquifer recharge).

Potential resources and required services in terms of soil and groundwater on existing BFs are summarized in figure 4. Available resources and required services are BF specific. Although the availability of resources and required services may change in time when a BF is regenerated, soil and groundwater may be re-used, especially when structural parts of the BF remain. The quality of available soil and groundwater resources is variable in time, depends on the source and is site-specific. The quality of waste water (process water) will depend mainly on the remediation processes applied and is, therefore system-specific. The quality of soil and groundwater depends on the contaminants level, geology, biogeochemistry and hydrogeological conditions of the BF as well as the upstream water quality. The quality of precipitated water is expected to vary between good and poor and depends on regional (or national) contaminant sources.

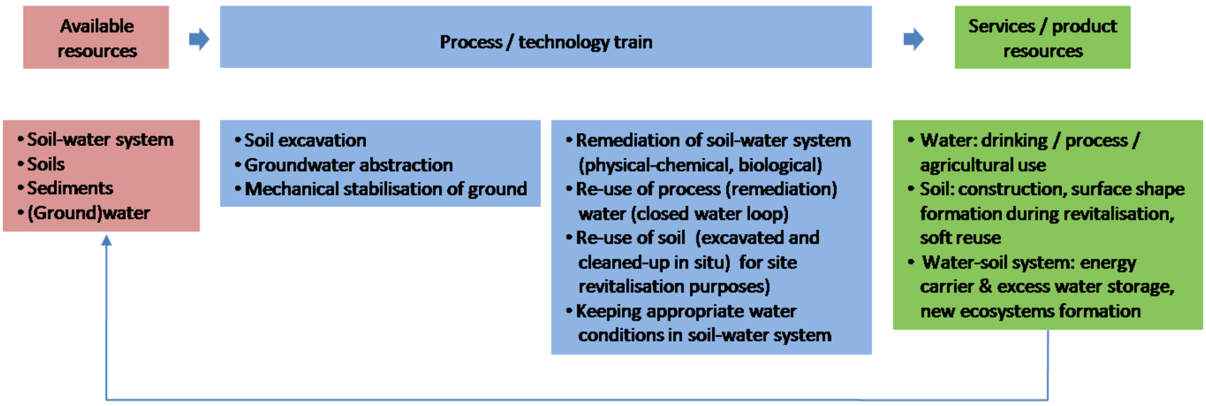


Figure 114: Soil – water system resources and services on BF

The required services mainly depend on the intended land use after BF regeneration. Ideally, detailed data of future land (soil) and groundwater use (in terms of both quality and quantity) are available but in most cases the intended use of the BF after regeneration is not known. For the exploration of possible, future use and the related soil and groundwater quality, and groundwater consumption (demand), some indicative values are required. Transformation of available resources into required services is to be performed through the 'technology trains'.

Soil quality problems are mainly associated with the presence of contaminants. Soil quality is a problem when non-contaminated (concentrations lower than a set-point) land is required, e.g. for residential and recreational purposes. If soil does not meet the standards it has to be replaced by clean material or cleaned-up.

Groundwater quality is a problem when high quality water is required but low quality groundwater is available, or when contaminated groundwater forms a risk for users and groundwater dependent ecosystems (GDE) as the receptors located within the BF areas or its surroundings.

Recent estimates show that there are ca. 130,000 cases of groundwater contamination in Europe, and additional ca. 3 million sites can be regarded as potential sources of contamination (EEA, 2007). Assuming remediation costs of ca. €300,000 per site, the replacement value of that unusable groundwater amounts to ca. 39 billions €. As the number of contaminated sites is predicted to rise to 270,000 by 2025, the replacement value may reach 81 billion € (Grima *et al.*, 2002). The socio-economic pressure is towards re-development of brownfields (BF) that are often sources of soil and groundwater contamination (Swickard, 2008). This is both relevant for countries where land scarcity limits the potential for further ‘greenfields’ development as for Eastern European countries with their legacy of contamination from abandon industrial and military activities, mainly from the so-called postindustrial areas, defined as degraded, abandoned, or not fully used areas previously designated for industrial/business activities that have been terminated (Malina, 2007a). They are degraded to a degree that limits the possibilities of development and/or returning to their previous economic functions. Re-development and re-vitalization may return these areas to communities, reducing consumption of ‘greenfields’, which is the key issue in terms of sustainability (Spira *et al.,* 2006). In the case of such areas contamination sources may be so heterogeneous, extensive or inaccessible that traditional remediation methods are not environmentally and socio-economically sustainable from the costs, performances and timescales viewpoint (Malina, 2006). On the contrary, sustainable remediation may integrate relevant technical, economic, social and environmental indicators to identify an acceptable balance with a net improvement to the environment, and involves the risk-based management and regulatory concepts.

While the shift to sustainable remediation over the last decade, has allowed the scope for evaluating remediation approaches to broaden to include energy, environmental and social components, the focus of in-situ remediation technologies has remained single-mindedly on the removal or reduction of contaminant concentrations or fluxes. However, the context of holistic brownfield redevelopment, provides an impetus for the development of in-situ soil and water technologies that, in addition to contaminant removal, contribute and integrate to a broader set of technical objectives during brownfield redevelopment. These additional objectives for in-situ technologies could particularly include needs subsurface goals during construction (e.g. foundations, dewatering or sealing).Within this perspective the in-situ creation of horizontal barriers would for example, also provide foundations for construction, and subsurface dewatering measures would be integrated with remedial efforts.

Groundwater quantity is a problem when the precipitation and inflow of ground and surface waters exceed the outflow of water from the river basin, where the BF of concern is located. It may lead to groundwater table elevation affecting some important functions of BF subsurface and surface infrastructure (e.g. wet cellars, local flooding of land) and/or terrestrial ecosystems. In contrast when the water inflow is lower than outflow, the water demands may exceed the available resources leading to lower groundwater table, and consequently to droughts affecting GDE at the BF area and the surroundings. Especially in urban areas, where the earth surface is sealed, heavy precipitation may lead to high water flow rates resulting in periodical flooding or mud streams when the drainage capacity is exceeded. Therefore, a possible service on BF level that can be thought of is the retention of water in the soil-water system to prevent flooding of downstream areas (soft land use).

4.2 Individual technologies currently used

4.2.1 Soil and water remediation technologies

Individual technologies for remediation of soil-water systems have been extensively described elsewhere, for example by the Federal Remediation Technologies Roundtable (FRTR). They include passive or active, *in situ* or *ex-situ* (*on site*), proven or innovative (under development), soil and groundwater remediation techniques. For the risk reduction a number of physical, chemical, biological and combined passive *in situ* measures may usually be applied rather than *ex-situ* unless, in the case of the so-called ”hot spots”, short-term safety measures are required. Using the methodology of source → pathway → receptor, technologies suitable for risk reduction can be classified as follows:

1. Prevention: by technical-organizational means the risk of contaminants entering the soil/water system can be minimized,
2. Contaminant control near hot-spots (contaminant sources): technologies that either recover spilled products or prevent the spreading of contaminants from hot-spots to more pristine (clean) areas,
3. Contaminant control and removal outside hot-spots: technologies that either immobilize or degrade contaminants to reduce risks.

<u>Prevention.</u>

- tight systems and installations to reduce emission of vapours/leakage from existing surface and subsurface infrastructure,

- monitoring systems for soil and groundwater quality and groundwater table elevation,
- modernization of waste and wastewater management.

Contaminant control near hot-spots

- skimming: free-phase recovery by means of selective collection devices: skimmers, bailers and special pumps,
- skimming with pump draw-down: hydraulically forced free-phase recovery,
- bioslurping (dual-phase recovery, dual-phase/multi-phase extraction, vacuum-enhanced extraction): simultaneous removal of free-phase, residual contaminants and vapours, vacuum applied enhances,
- physical containment/isolation/passive treatment walls: to limit contaminant transport (slurry walls, grout curtains, viscous liquid barrier, sheet piles, etc.),
- hydraulic barriers: hydrodynamic field modification by means of groundwater extraction (wells, drains, drainage ditches),
- permeable reactive barriers: creating zones with enhanced physical-chemical processes (e.g. sorption, chemical oxidation) and biological activities (e.g. biodegradation, bioprecipitation, biosorption) by supplying microorganisms, additional electron acceptors and/or organic carbon and nutrient sources.

Contaminant control and removal outside hot-spots

- natural attenuation (NA): a set of natural (geogenic) processes reducing contaminants concentration with no additional stimulation: (i) destructive processes: biodegradation, chemical degradation, photo degradation, transformation, (bio)transformation, humification, etc., (ii) non-destructive processes: dilution, filtration, immobilisation through (bio)sorption/ion-exchange/(bio)precipitation, evaporation, diffusion, dispersion, etc.,
- monitored natural attenuation (MNA), or barrier-controlled monitored natural attenuation (BCMNA): controlling/monitoring geogenic processes to predict/prevent the contaminants spreading in groundwater,
- enhanced natural attenuation (ENA): limited use of plume control and/or active/passive remedial techniques to stimulate self-purification processes in soil and groundwater; NA can be enhanced by a number of the cost-effective measures, including for example: (i) oxidation, (ii) phytoremediation, (iii), pump-and-treat, and (iv) permeable reactive barriers

Depending on site-specific properties as site-geology and hydrology, cost-effective soil and groundwater remediation measures thus include: pump and treat (P&T), (bio)venting, soil vapour extraction (SVE), biosparging, bioslurping, physical containment, isolation, solidification, non-permeable slurry walls, hydraulic barriers, permeable reactive barriers (PRB), biological barriers, bioscreens, biowalls, bioremediation, soil washing, *in situ* chemical oxidation ISCO). Some available measures that can be used to enhance NA during BF re-generation projects are summarized in figure 15(Malina, 2007b).Unfortunately, the practical implementation of NA - and ISR - based sustainable remediation in Europe is limited mainly due to: (i) stakeholder awareness of available methods, technical feasibility and confidence in application; (ii) different inclusion in decision-support processes; (iii) different qualitative and quantitative indicators of performance and comparison with traditional measures; and (iv) lack of guidance and decision-supporting frameworks and tools (Spira, 2006; Onwubuya, 2009). This approach is often undertaken without a clear understanding of the fundamental science, technical basis and performance assessment framework for reliable decision-making. This is due to different recommendations of environmental legislation within the EU compared to the WFD, and the lack of professionals with the skills required to implement the MNA and ISR in practice. Consequently, it is often difficult to deduce the reason for successful or failed remediation, which undermines end-user confidence. Currently, this gap prevents the wider use of MNA and ISR for sustainable contaminated land management within Europe and worldwide. A key challenge concerning sustainable remediation is to more closely integrate the various scientific, technical and socio-economic aspects. The integration of the same aspects is also required for improved BF re-development approaches, but at a larger, spatial scale.

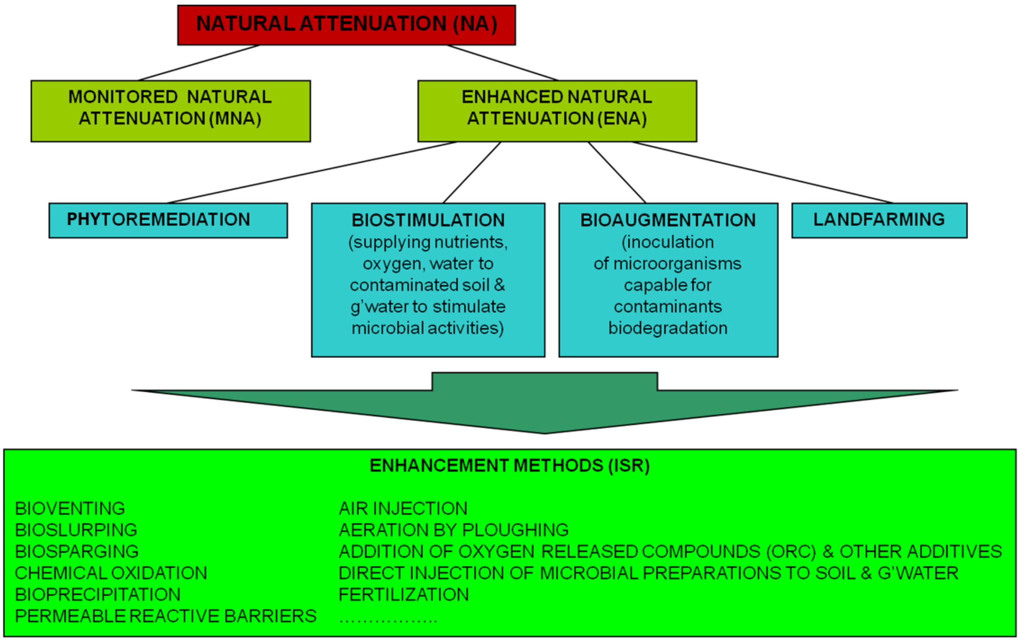


Figure 15: Some available processes and methods for enhancing NA (Malina, 2007b).

The application of these technologies benefits from various factors, including good accessibility either for injection or characterization purposes. This accessibility is not always available either at an actively re-developed BF due to competition with the building activities, or at a dormant BF due to the presence of legacy infrastructure and buildings. Although advances in for example directional drilling have made accessibility improvements for the contaminants characterization and remedial agents delivery, these are relatively expensive and employed despite of BF re-development activities rather than integrated in the overall BF redevelopment strategy.

One of the most immediate contamination risks for a redeveloped brownfield is the threat posed by vapour intrusion of (remaining) contaminants through the vadose zone and associated human health risks for users. Currently, limited options exist for the mitigation of contaminant vapour risks, the main ones being physical measures of either sealing off the surface by geotextiles or other materials, or the installation of (continuous) active ventilation installations. Both approaches have severe limitations. Sealing of the surface for instance prevents (rain) water infiltration and therefore requires additional water management measures at site, while the use active ventilation for example requires indefinitely regular operational monitoring for functioning and effectiveness.

4.2.2 Present limitations and shortcomings individual technologies

The presence of contamination in the soil/water system either prevents the start of BF re-development, or is dealt with 'ad-hoc' towards the end of the re-development phase, when re-development flexibility (e.g. time and planning design) is minimal. Under these conditions the use of conventional, energy intensive remediation approaches such as 'dig and dump' are typically favoured as NA or ISR technologies are generally unable to provide "clean sheets" for re-development.

This conventional approach is unwanted from time, costs and sustainability viewpoints. As concerns sustainability, a shift in this practice is required as solving the environmental problems may create an opportunity not only for the BF itself but also for the neighborhood by providing services and benefits required within and/or out of the site. The re-development approach must therefore go beyond the individual site scale and include a wider (local or regional and in time) perspective and start with identifying the services required within and/or out of the BF prior to selecting the 'technology train(s)' capable of providing them.

On the other hand, to increase the BF potential, dealing with soil and groundwater contamination should become an integral part of the overall re-development project. For this purpose, the current remediation technologies should be adapted and integrated, or new ones need to be developed. within “technology trains” with clear environmental and socio-economic benefits (e.g. lower energy and resources demands, waste generation, carbon footprint and contribution to climate change). The ‘technology trains’ should also be built in such a way that joint clean-up of soil and groundwater could be done, which is much more effective than their separate remediation. This will allow contributing both issues to short-term conditions required for the planned use of the BF, as well as the long-term objective as indicated in both: Soil Thematic Strategy and Water Framework Strategy.

Ideally, the consideration of the presence of contamination and remediation approach becomes an integral part of planning a BF re-development strategy. Unlike in a ’clean-sheet’ approach, planning BF re-development with the presence of contamination in mind will provide design challenges by spatial and other constraints, as well as opportunities for the design itself to mitigate the contaminant situation. As for the re-development planning itself, site specific investigations are essential for the evaluation of NA and ISR and the effectiveness of alternative or additional measures. This allows the assessment of the management of risks associated with the contamination for the intended use of the redeveloped BF, as well for more distant receptors, now and in the future (as for WFD).

The BF re-development from a ‘clean-sheet’ perspective provides fewer constraints on re-development possibilities, design and functions. *Ex-situ* soil remediation is a quite simple and fast technology with elevated costs. However, until any lingering soil and water issues are dealt with satisfactorily in the perspectives of future users (e.g. residents), nearby stakeholders (e.g. ‘neighbors’) and long-term receptors (e.g. drinking water wells), a BF is not fully revitalized and returned to the land-use cycle.

4.3 Opportunities technology trains soil-water

The prospect of sustainable remediation has forced the development of contaminated land management concepts, particularly for large and complex contaminated sites during last decade. Consequently, the conscious and controlled use of naturally occurring degradation and retardation processes of contaminants in the subsurface (natural attenuation - NA), accompanied (if required) with *in situ* remediation (ISR) have gained increasing attention. Such ‘treatment trains’[7] seem to be effective to deal with complex contamination problems at BF with clear environmental and socio-economic benefits (e.g. lower energy and resources demands, waste generation, carbon footprint and contribution to climate change) (Malina, 2008; www.frtr.gov/matrix2). A major European driver for applying these technologies is the Water Framework Directive (EU-WFD, 2000) which provides a legal framework to protect and restore clean water in Europe and ensure its long-term and sustainable use, based on achievement of ’good status’ for water bodies by 2015, using quality and quantity-based criteria. (WISE Water Note 3). The WFD includes objectives to reduce contamination from ’priority substances’, prevent deterioration of chemical status and gradually reduce groundwater pollution. It also requires the reversal of increased trends of pollutant concentrations in groundwater. However, ca. 30-60% of the groundwater bodies in the EU are reported to be at risk of not achieving ’good status’ by 2015 (Duffield *et al.,* 2000). This is a significant driving force for remediation of contaminated sites, particularly with many contamination sources and diverse pollutants. It is important to note, however, that these technologies have not been developed or specifically applied to aid the BF re-development potential. Instead, the main focus mainly originated from a narrow engineering perspective, focusing on the intended interaction between contaminant and remedial agents and consequent contaminant concentration reduction.

Integrated spatial and temporal planning

To increase BF re-development potential, dealing with soil and groundwater contamination should become an integral part of plans for the re-development of industrial locations or derelict urban sites. For this, the use of current remediation technologies should be adapted or new ones need to be developed. One particular approach for making soil and groundwater remediation efforts more an integral part of brownfield remediation, is to consider the other subsurface technologies used either during or after brownfield redevelopment. One example of this is the potential for combining ATES energy systems with groundwater remediation (as discussed in Chapter 2). For the soil-and water train, the use of foundation technologies (such as jet-grouting) during brownfield redevelopment may

[7] A 'treatment train' is related to the soil/groundwater sequential remediation (e.g. see: www.frtr.gov/matrix2), while a ‘technology train’ has a broader sense as it includes also other options for BF regeneration (e.g. re-use of C&D waste)

provide potential for integration with sustainable in-situ remediation approaches. At the same time, this provides an opportunity to make grouting technologies more sustainable, as the majority of jet-grouting uses chemical grouts containing substances as cement or water glass. The natural basis for making grouting techniques more sustainable could come by using and stimulating natural processes that result in the desired changes of the physical and mechanical properties of soil by influencing and speeding. However, so far sustainable grouting technologies that integrate remedial potential are lacking and provide a clear opportunity for technological innovation, for example for sustainable technologies that provide both physical and/or mechanical improvement that allow the creation of foundations for construction as well as providing remedial solutions during and contaminant risk reduction after brownfield redevelopment.

Which particular NA and ISR technologies are applied depends strongly on site- and conditions specific characteristics, as well as the ambitions for the future use of the BF. As the level of risk that contaminants pose at the BF site is a major factor in determining the potential for its use, remediation technologies that mitigate risk are more favourable than technologies that merely remove contaminant mass. In addition, most re-development activity occurs at (e.g. paving) or just below the ground surface (e.g. drainage system). Therefore, technologies that can be applied in the unsaturated or shallow groundwater zones have a larger potential to be integrated into the overall re-development planning. For technologies that target deeper contamination, combinations re-development activity at greater depths, such as foundation work and excavation, can be made. The aim of these technologies can be to protect or enhance the occurrence of NA or to introduce of remedial agents to reduce risks (see the EU WELCOME project).

A direct implication of the fact that complete removal of the contamination source is in many cases not possible, is the need for long-term management going beyond the time-scale of traditional remediation activities. By integrating remediation objectives into the BF re-development planning, the NA and ISR -based sustainable remediation approaches can be easily incorporated in existing management concepts. This will allow contributing both to shorter-term conditions required for the planned use of the BF as well as the longer-term objective, such as in the context of the WFD. In this case, NA-based sustainable remediation with, or without stimulation by means of ISR can be regarded as a practical and cost-effective approach for sustainable management of contaminated land, particularly in terms of the “proportionality” principle contained in WFD. This avoids restrictions on remediation time-scale and target values, and forecasting additional measures, if required. In addition, it can identify possibilities to reduce negative effects on receptors that would otherwise not be considered, if water and soil contamination was not integrated in the overall BF re-development planning. In this way, the combination of goals and risk-based management with spatial planning is allowed with the BF re-development.

Risk based
The main aspect for BF remediation is the mitigation of risk for its future use. The more these risks can be reduced, the higher the level of future use can be planned. Besides the risk to the future users of the re-developed BF, also risks to nearby uses (neighborhood) should be addressed. A key issue determining the potential risks of contaminants is the rate with which the contaminants are spreading vertically and horizontally in both unsaturated and saturated zones (with groundwater flow). The occurrence and rate of NA processes is a key factor that determines the risk of contaminants spreading. Moreover, the NA assessment is necessary to evaluate the need for increased contamination control using active/intensive and/or passive/extensive ISR measures. If the rate of contamination plume movement (spreading) in soil and groundwater is lower than the value of assumed parameter defining the overall rate of observed biogeochemical processes, there is the potential to base remediation (risk reduction) at this particular site on NA, in other case these processes should be enhanced by ISR techniques (Malina 2007b). The extent to which contaminant and associated risk removal can be enhanced, depends largely on site specific conditions (e.g. a contaminant type, hydrogeological and redox conditions).

Synergies
In the context of sustainability a shift in this practice is required: solving the environmental problems associated to a BF may create an opportunity not only for the site itself but also for the neighborhood. Consequently, the BF as such may provide services and benefits that may be required within the BF and also out of the site (in the surroundings). This forces that the approach for BF regeneration must

go beyond the individual BF site and take into account a wider perspective (local or even regional scale). Therefore, the novel approach in the selection of the most effective and sustainable BF regeneration must start with identifying the services (needs/opportunities/outputs) in the BF itself and/or in the surroundings prior to selecting the 'technology train(s)' capable of providing these services.

Re-development/revitalization may return BF to communities, reducing consumption of 'greenfields', which is the key issue in terms of sustainability, but it usually requires remediation of soil and/or groundwater. Therefore, another important issue for sustainable redevelopment of BF is to look for proper measures to clean up contaminated soil and groundwater in an effective way. Traditional remediation methods usually comprise: energy and water consumption, waste, greenhouse gases and/or toxic substances production and release to the environment, thus are not sustainable. Sustainable remediation should integrate relevant technical, economic, social and environmental indicators to identify an acceptable balance, which delivers 'net' benefits, i.e. a 'net' improvement to the environment. Sustainable remediation may be based on MNA enhanced (if needed) by the existing ISR (see chapter above). Soil excavation needs also be considered in some particular locations (e.g. 'hot spots'), but the way to reuse it should be clearly defined in advance.

Experiences show that effective remediation of soil and groundwater at BF can only be done, if combined measures are applied rather than one particular remediation method. Therefore, there is a need to use the "treatment trains" approach to deal with complex soil and groundwater contamination problems at BF, with clear environmental and socio-economic benefits (e.g. lower energy and resources demands, waste generation, carbon footprint and contribution to climate change). Moreover, the 'treatment trains' should also be built in such a way that joint clean-up of soil and groundwater could be done, which is much more effective than their separate remediation.

Sustainable remediation should thus be integrated within the planning for sustainable re-development of BFs, which encompasses: (i) risk-based contaminated land management, (ii) involvement of stakeholders, (iii) transparency of decision making processes, (iv) balanced outcomes in terms of the environmental, social and economic elements of sustainable development, and introduce the opportunities and scenarios in an earlier stage of the planning activities.

In all these aspects, the perception of risk plays a pivotal role, in which new or adapted soil and water technologies for removing or reducing risks by physical or (bio)geochemical means can provide an important contribution. The challenge of sustainable BF re-development is then to provide solutions, which offer benefits to involved parties, while minimizing the negative consequences and associated risks. It requires: planning, preparing decisions, implementing solutions, applying technologies and optimizing performance site-specifically and continuously.

4.3.1 Application of soil-water technology train in case studies

So far in the Solec Kujawski BF regeneration project the following regeneration scenarios of soil (and groundwater) remediation concepts were considered (Irmiński, Debicka, 2010): (i) remediation ex situ, (ii) remediation *in situ*, (iii) combined *in situ* / ex situ / on-site remediation.

According to the first approach the contaminated soil should be excavated and placed to the depositories or to external remediation plant (a remediation plate). The material output would be: ca. 603,800 m^3 of contaminated soils and C&D waste from the area of ca. 151,200 m^2, with the depth of excavation of ca. 4 m. In the Solec Kujawski region no ex situ remediation plant exists that is enough big and effective to be used for this purpose. This option demands equal amounts of not contaminated soil as an input. Apart from high costs of excavation and removing of polluted materials, the input of clean soil along with soil compacting are not sustainable from costs an energy consumption viewpoint. Moreover, it would need cutting of all existing trees and stabilization of the borders. Finally, temporary storage of excavated soil contaminated with creosote is not easy to handle due to vaporization of the impregnation oils that result in emission of strong jarring smell.

Two other concepts are based on the use of bio-preparations for destroying the components of creosote in soil and groundwater. As it is possible to relatively easily distinguish the contamination sources, secondary contamination and not polluted parts (in the aeration zone), the *in situ* cleaning concept assumes minimal excavating works (without hauling soil off site). The goals are: flattening the area, preparation of big bioremediation fields and equal treating of the whole area (bacteria inoculation, fertilizing). In this concept the majority of the trees (especially big trees) may remain unattached. However, the C&D waste (concrete and bricks rubble, scrap-metal and collected hazardous waste – creosote pitch) has to be removed off site before the bioremediation phase. In addition, bioremediation is expected to be long, uneven and costly (biopreparation and fertilizer costs). Moreover, it may lead to significant and uncontrolled increase of hydrocarbons concentration in the saturation zone.

The *in situ* / ex situ / on site soil and groundwater remediation approach in the Solec Kujawski BF is based on:

- segregation of C&D waste and preparation of the homogenous rubble of contaminated and not contaminated materials for the re-use on site,
- hauling the recyclable materials with a market value off-site (scrap-metal) and thermal treatment of hazardous wastes (creosote pitch),
- excavation of heavily contaminated soils that, together with the contaminated rubble become building materials for the bioremediation prisms; an input of soil for the prisms covering for the improvement of biological process is needed,
- filling the excavated places with local (on-site) soil material (e.g. from flattening of the area), small fraction of clean concrete and bricks rubble (ca. 800-1000 m^3 soil needed),
- construction of bioremediation fields/ponds in the zones with medium and secondary soil contamination (zones under existing soil/rubble/waste dumps),
- bioremediation in the ponds and in the prisms with the use and control of the local groundwater; it would give the opportunity to remediate the contaminated water and allow for effective use of biopreparations and fertilizers.

Following this concept, the majority of vegetal cover (trees) would be secure, while the bioprisms would become part of the planned area morphology.

An additional combination of remediation techniques, which can support the soil clean-up, comprises washing of the soil excavated from heavy polluted zones that can significantly reduce the contaminants concentration. Sludge from washing as a hazardous waste has to be removed from the BF and treated off site in the same way as a creosote pitch (thermal utilization). Homogenization of the soil (after the washing phase) is easier and accelerates the bioremediation process in the prisms. This combination (‘treatment trains’), is considered, however, it is not possible to clean up the soil within the whole aeration zone (ca. 4,5-5 m deep). Moreover, the washing chemicals are out of control, and according to the Polish regulations (Environmental Protection Law), introduction into soil any alien non-natural substance is not permitted.

The owner of the Solec Kujawski BF has not undertaken any remediation works to date due to the economical reason. Such investments require the external funding (e.g. from regional or national budget).

In the Solec Kujawski BF (mainly contaminated soils and C&D), the current approach is based on ‘dig and dump’, making the remediation unaffordable. In this novel approach, the following services can be considered:

- landscaping of the site with new road/paved areas and infrastructure construction according to the BF re-development plan,
- recyclable material re-used on site or sold off site,
- bioremediation piles on site as a part of landscape of BF being re-developed.

The technology trains(s) will have to be compared in terms of indicators of success based on the capacity of improving the environmental footprint and socio-economic benefits as compared to the conventional solution. As an example, in the Solec Kujawski BF the reduction is possible of abiotic resource use and land use, together with the costs of contaminated soil and groundwater sustainable remediation required for BF regeneration.

5 Conclusions

Integration of the technology choice within the BF regeneration pathway.
One of the main issues that often delays the BF regeneration process is the separation between the decision process related to the solution of the environmental problems and that related to the choice of the new end-use(s) of the BF within the city planning / urban architecture process. This is often due to the lack of links between the environmental and urban legislation that makes it difficult to apply an integrated or holistic approach to the redevelopment process. Often, in BF sites the solution of the environmental issues needs to be developed when the ideas on the redevelopment of the area are still unclear. This may lead, for example, to the selection of over-conservative clean-up goals, that may increase the remediation costs to unaffordable values, thus hindering the whole BF regeneration project. On the other hand, it could be in principle possible that a given redevelopment strategy (i.e. the choice of a specific end use for a site) cannot be met at reasonable costs, given the efforts required to clean-up the site at the required target. Summarizing, the selected end use(s) surely affect the regeneration (and remediation) pathway and the selection of the technologies (either for soft or hard land-use of the site), but also the reverse may apply in more than one case.

These observations suggest that the choice of the new end use(s) of the BF should be as much as possible integrated in a holistic approach with the choice of the regeneration (and remediation) pathway. Possibly, at least a pre-screening of the regeneration technologies should be available at the stage of master-plan definition, in order to eventually remove already at this stage those options that would be technically or financially unfeasible. Early collaboration between technology experts, landscape architects and spatial planners is essential to seek opportunities that BFs provide. Starting too late limit the possibilities, increases costs and puts acceptance of end-users at risk. Soil/water cleaning will be expensive and not sustainable. Furthermore early corporation allows implementation of instruments to use either soft-technologies/land use and hard technologies/end use. Early input of technologies in planning BF reuse increase possibilities for costs and risks reduction.

Integration of technologies (Technology trains)
The start point of technology integration is a baseline assessment on the properties of the BF and its surroundings, including the identification of potential resources. Once some information regarding the intended use becomes available the required goods and services can be estimated, and crude calculations (using estimates or national averages) can be made regarding the environmental quality of soil, water, and air, the energy use, and the water consumption. From that point, optimization of technologies and land use becomes important. This optimization will probably be in a form of iterative or adaptive design. Optimization of technologies includes the coupling of technologies. This coupling or integration can be performed on three levels:

1. **(simple) Technology train** is the combination of individual technologies (wagons) forming a technology train to provide the required service or good from a fixed (combination) of resources.
2. **Integrated Technology train** is the combination of individual technologies to provide more than one services or goods from a combination of resources. It can be expected that the efficiency (technological) of the process to produce a single service or good is lower compared to a (simple) technology train that is specialized to provide that single service or good but higher when multiple services or goods are produced.
3. **Holistic technology train** is when we have more technology trains that can be properly integrated to provide multiple services using multiple resources for more than one sector (contaminated materials and energy).

The development of technology trains is feasible within HOMBRE but require extended knowledge regarding the next use phase and local operating windows, especially legislation. As a concept the technology trains will give added value to the process of brownfield regeneration (doing better, faster when needed but slower (cheaper) when possible, cheaper and generating less harm and nuisance to the surrounding in the BF regeneration phase) and pave the way for a more sustainable new use on the site (with connection to local area providing renewable energy, optimized material recycling, tailored water solutions…).

Boundaries of technology choices

A major difficulty in the design of technology trains is the country specific legislation, especially regarding the soil, C&D waste, water and groundwater system. Also the possibility to use waste on-site or off-site strongly depends on national legislation. The optimal remediation or re-use strategy is therefore country specific. For a generic design of technology trains this can be tackled by defining legislation as boundary condition. Case studies can then be tested for the generic principle although the implementation of a specific technology train might be difficult or even impossible. HOMBRE can then act as catalyst in the discussion with policy makers. Knowledge transfer may pave the road to remove present barriers when benefits and negative effects (environmental, societal and economic) can be demonstrated and discussed for a specific BF case.

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Abbreviations

ATES: Aquifer Thermal Energy Storage

BAS: Business as Usual

BAT: Best Available Technologies

BOF: Basic Oxygen Furnace

BF: Brownfield

C&D waste: Waste produced during construction and/or demolition of buildings and infrastructures

EAF: Electric Arc Furnace

EWC: European Waste Catalogue

HBM: Hydraulically Bound Mixture

ISCO: In Situ Chemical Oxidation

ISR: In Situ Remediation

MNA: Monitored Natural Attenuation

MSWI: Municipal Solid Waste Incinerator

NA: Natural Attenuation

PAHs: Polycyclic Aromatic Hydrocarbons

PCBs: PolyChlorinated Biphenyls

PRB: Permeable Reactive Barrier

P&T: Pump and Treat

S/S: Solidification/Stabilization

SVOCs: Semi – Volatile Organic Compounds

VOCs: Volatile Organic Compounds

WFD: EU Water Framework Directive

Annex 1

Fixed Plant

Treatment Plants Waste.
Management still very heterogeneous.
The heterogeneity of the CD&W forces to equip the plant with machinery of great strength and oversized for the expected nominal capacity in other applications.

Type	Advantages	Disadvantages	Applications
Jaw crusher and impactor (1 or2).	▪ Combines the Advantages of both types of crushers. ▪ Large capacity. ▪ crush concrete Waste large.	▪ High investment Costs.	▪ Suitable for large Quantity combined With quality Products demand.
Jaw crusher and cone.	▪ Product of very good quality, strong, cube-shaped. ▪ Low attrition rate.	▪ Susceptible to Bars and scrap Metal in the Disposer of how. ▪ High investment Costs.	▪ Recommended for secondary raw materials of high quality
Impactor drum sieve.	▪ Especially good for handling large masses of concrete.	▪ High wear ▪ High cost Investment.	▪ Is the ideal combination for residues of recycled concrete, railway, sleepers, beams, concrete floors.

Semi mobileand **mobileplants**

The mobile plants have the advantage of temporarily placement in the waste generation centres with high availability at full load.

Moved for a track system (self-propelled) or pneumatic wheels (need tractor for transportation). The track system is more expensive and is designed for the frequent transfer of the equipment on uneven terrain and in poor condition. For the transfer of machinery for various fixed locations separated by great distances, it is recommended tire system.

Mobile or semi-mobile plants are:
More expensive than fixed per unit of tonnage Treated due to its compactness and motion system.
They are also more selective in their compactness and motion system.
Are more selective about the type and size of Debris treaty, being limited to the quality of its products, including unit Operations
They tend to be modular, so you can collect different items as needed.

Type	Advantages	Disadvantages	Applications
Jaw Crusher	▪ Simple, rugged construction ▪ Low wear ▪ Crush the hardest rock	▪ Low efficiency grinding ▪ Problems with bituminous pavement ▪ Virtually impossible to recycle large size	▪ no problem crushing debris ▪ No quality requirements or Production capacity.
impact crusher	▪ Effectiveness crushing all kinds of construction debris and pavements	▪ Relatively high rate of Attrition ▪ You can generate excess fines problems with bituminous material jams	▪ Suitable for all types of crushed rubble ▪ High capacity

Differences between a FIXED PLANT and a MOBILE PLANT

- Transportation: A plant has an extra set, very important with regard to mobility. Since the latter lacks transportation, doing, in most cases, the recycled "in situ". This extra cost is a very important value in the process, since it is one of the most expensive components in the total cost of recycling; understanding component transport, processing, energy, maintenance and staff. All these components are more expensive in mobiles and semi mobiles plants than fixed. The price of transport can sometimes be superior to the canon of the spill or the price of raw materials resulting from this process. Therefore, the treatment plant must be close enough to urban centres for the cost of transport of the waste is not burdensome and incentive to the manager for deposit in the plant. Yet, mobile plants also have a cost of packing and transportation of equipment to the place where they will be employed.
- Cost of land: Much of the profitability of a treatment plant depends on the investment in the purchase or leasing of land, so that the plants still have a major cost in this section because it takes a lot of surface and ground today. These days, it’s a scarce and highly valued. Mobiles plants do not have this problem, as they usually are installed in the same work.
- Civil works: The amount of civil works for a fixed plant is another of those who do not have a mobile plant. The investment required in this section include the following items: earthwork, access, connections, fencing and foundations (the plant requires a perimeter fence to reduce the environmental impact)
- Installation: The recycling plant set is more complete and far more expensive than a mobile plant. To include allocations for: structures, boilers and pipes mechanical and electrical assemblies, scale, and changing cabin reception, and office equipment. In addition, there are costs of fixed and mobile, fixed and mobile plant respectively.
- Permits: licenses and environmental requirements: Those for a fixed plant are very demanding, not having this problem with the mobile plant.
- Cost and maintenance personnel: The fixed plant has higher costs than mobile plant.
- Energy expenditure: Mayor in a fixed plant.

ON-SITE crushing and sorting:

ADVANTAGES	DISADVANTAGES
Lower materials handling and transport costs Lower machinery capital costs Less transport disruption to surrounding areas (if recycled materials can be used on-site)	Conflicts between site operations and space demands for materials and machinery. Higher machinery operating costs per tonne of C&DW. More local noise and dust nuisance. Less flexibility about where/when recycled materials can be used. Construction may be delayed

Operators of on-site crushers are often under pressure to treat whatever materials are placed in front of them, and to make the resultant C&DW-derived aggregates available for the construction process as quickly as possible.

OFF-SITE crushing and sorting:	
ADVANTAGES	**DISADVANTAGES**
Easier to reduce and/or mitigate adverse environmental impacts on surrounding areas.	Proper control of demolition process essential (to avoid arrival of unknown quality materials)
More practical to use a wider range of higher capacity equipment.	Higher materials handling and transport costs.
Lower machinery operating costs per tonne of C&DW.	Higher machinery capital costs.
Easier to control quality of recycled materials.	fixed costs of recycling the site (land etc)
Possible to hold stocks, thereby making positive marketing of recycled materials easier	

Larger off-site crushing and sorting facilities can operate much more like conventional aggregates quarries, building up stocks of different specification materials which enable them to supply larger contracts without delay. Some operators blend primary and C&DW-derived aggregates, and there is increasing evidence of primary aggregates operators now entering the C&DW recycling sector in the UK, in Italy and in Spain.

Off-site facilities can also take long enough over the processing to ensure that the amounts of wood, plastic wastes and other contaminants getting into the final products are kept to an acceptable minimum.

Off-site crushing and sorting plants which accept C&DW from third parties may well have a problem with irregular and unpredictable raw materials (which may or may not contain hazardous or at least non-inert fractions as a result of the professionalism with which the structure was demolished, irrespective of the nature and content of the original building). Some plant owners overcome this by controlling the demolition process (if it is done by third parties) through close on-site liaison with the demolition contractor. Others rely mainly on careful, and sometimes multiple, inspections of the incoming materials prior to and during processing. Others simply use a central facility to deal with the waste from all their own local demolition sites, rather than operating mobile plants at each, and do not accept any C&DW from third parties.

The point about quality appears to be very important. Even in those Member States where C&DW-derived aggregates are already relatively widely used, the main barrier to greater market acceptance appears to be potential buyer’s doubts about their quality and consistency rather than a lack of formal standards for recycled materials. In some countries there is now a move among C&DW derived aggregates producers to institute external quality verification procedures (typically involving cooperation with an independent materials testing laboratory), thereby allowing their products to benefit from a quality mark.