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EcoWater report

Innovative technologies for enhancing the eco-efficiency of water use in industries

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SEVENTH FRAMEWORK
PROGRAMME

Meso-level eco-efficiency indicators to assess technologies and their uptake in water use sectors

Collaborative project, Grant Agreement No: 282882

Deliverable 4.3

Innovative technologies for enhancing the eco-efficiency of water use in industries

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Abstract

This deliverable contains information about innovative technologies with the potential to increase eco-efficiency in the industrial sector. Technologies were identified according to the environmentally weak stages in each of the four Case Studies examined.

The technologies are classified according to the stage at which they are implemented:

- Technologies in the water supply chain (common in all water use systems); implemented either upstream (e.g. water treatment) or downstream (e.g. wastewater treatment) of the water use stage.
- Technologies in the production chain.

The technical description provided includes information about the working mechanisms, the environmental performance, cost data, technological maturity and justification for the necessity of each technology presented.

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1 Introduction

The aim of Deliverable 4.3 is to describe potential technologies and practices for improving the eco-efficiency of the four industrial water use systems, in terms of anticipated impacts, costs, and effectiveness in mitigating environmental impacts and minimizing resource use.

This Deliverable is the outcome of Task 4.3 and is an intermediate step between Phases 2 and 3 of the Case Study Development. In Phase 2 all the environmentally and economically weak stages/processes of each system have been identified. Task 4.3 identifies innovative technologies that could potentially improve the economic and/or the environmental performance of the studied system. These technologies will be assessed in the 3rd Phase of the CS Development.

In general, the technologies are classified according to the stage at which they are implemented:

- Technologies in the water supply chain (common in all water use systems); implemented either upstream (e.g. water treatment) or downstream (e.g. wastewater treatment) of the water use stage.
- Technologies in the production chain.

In the industrial sector the 4 production chains have very few common characteristics, concerning either the processes involved or the quality/quantity of water required; there are no common technologies among all four Case Studies.

In the Biella Textile Industry (CS#5), the focus is on the process of dyeing and the aim is to identify innovative technologies for the treatment of industrial wastewater, particularly those that will affect the outgoing wastewater in terms of quality and ecological sustainability rather than in terms of quantity.

For the analysis of the cogeneration plant in the Amsterdam-Rhine canal (CS#6), the main focus is to identify technologies that will reduce the large amount of thermal discharges of cooling water, which cause serious problems to ecosystem biodiversity.

In Case Studies #7 and #8, the analysis focuses around the water use stage (actors Arla and Volvo Trucks, respectively), as this was identified as the environmentally weakest stage in both systems. In the Arla Dairy Industry (CS#7), emphasis will be given on the processes with higher water and energy consumption, while in the Automotive Industry the aim will be to reduce energy consumption and the amount of pollutants emitted to wastewater.

The following sections present the list of innovative technologies for each one of the four Case Studies, and provide information about the working mechanisms, the environmental performance, cost data, technological maturity and justification for the necessity of each technology.

2 Innovative technologies for Case Study #5: Biella, Textile Industry

The textile industry processes are responsible for the production of large amounts of toxic and stable pollutants, which are all collected into the wastewater treatment plant. The disposal of these contaminated effluents into receiving water bodies can cause significant environmental damage, directly influencing the aquatic ecosystem and even human health.

Textile Wastewater (TWW) discharged from dyeing processes is characterized by highly fluctuating pH, high temperatures, a considerable amount of Suspended Solids (SS) and degradable organics, high Chemical Oxygen Demand (COD) and color concentrations, nutrients, salts, toxicants and non-biodegradable substances such as additives, detergents, surfactants, and dyes.

Thus, the focus in the Case Study of the Textile Industry in Biella is on the innovative technologies concerning the treatment of industrial wastewater and particularly those that will affect the outgoing wastewater in terms of quality and ecological sustainability rather than in terms of quantity. This is due to the fact that water losses into the production chain processes are minimal compared to the quality degradation from the freshwater. The objective of the Case Study is also to provide knowledge on new technologies in the textile industry, which may reduce the quantity of sludge for incineration and increase the quality of sludge for agriculture.

Furthermore, the textile industry is one of the most fragmented and heterogeneous sectors because it is mainly characterized by small and medium enterprises (SMEs). The cost of supplementary resources, and especially energy, is one of the main expenses of a textile plant (Hasanbeigi, 2010). Thus, in order to improve the overall eco-efficiency, new energy saving technologies should be promoted.

The Biella Case study is oriented towards the part of the textile industry called "wet processing", and in particular to the process of dyeing. The selection of technologies was made on the base of the above mentioned characteristics that can be representative of the Biella textile industries, taking into account the innovative technologies already installed in the units.

2.1 Production Chain Technologies

2.1.1 Jet Dyeing Machines

Description

Figure 1. Low-Liquor Jet Dyeing machine (Cotton Inc., 2009)

A jet dyeing machine operates by forcibly contacting the cloth to the jet flow of dyestuff solution. The tension on the cloth is decreased as much as possible and the cloth dyes evenly with a lower amount of dyes (compared to the conventional dyers).

The principle of jet dyers is the acceleration of water through a nozzle to transport fabrics. Jet dyers are operated with liquor ratios less than 1:8 or even 1:12. These machines belong to the category of batch dyeing machines and operate under high temperatures (maximum temperature ranges between 135 and 140°C). The low liquor ratio contributes significantly to achieve short times in the wet processing resulting in a cost reduction.

Based on the liquor ratio, these machines can be divided in four different categories (Chandna, n.d.):

- Partially filled with liquor, suitable for treating PET, PA or synthetic fabrics
- Completely filled with liquor, used for more delicate fabrics
- Overflow Jet Dyeing Machines
- Air-flow (Air Jet) Dyeing Machines

Economic Data

The investment cost of such a technology ranges from 150,000 to 300,000€ (Cotton Inc., 2009). The payback period is estimated to be 2-5 years (EBSCO).

Environmental Performance

The optimized jet dyeing machines support a more sustainable fabric production in mills. The literature review indicates that jet dyeing machines save almost 50% of water used in wet process (Cotton Inc., 2009). The reduced liquor ratio guarantees optimal dyeing results in very short times, enhancing reduction of water consumption and quantities of auxiliaries. Furthermore, short times in production allow energy saving up to almost 40%, comparing with other conventional techniques.

Maturity and Availability

Jet dyeing machines have been used commercially for 40 years and are considered a mature technology.

2.1.2 Automatic Dye and Chemical Dispensing

Description

An automatic dye and chemical dispensing system consists of automatic and semi-automatic weighing, dissolving, and measuring systems in order to facilitate the precise delivery of textile chemicals and dyes to production machines, as well as to laboratory machines for shade and sample development (Cotton Inc., 2009). Such systems can be used for handling both liquid and powdered substances.

Figure 2. Automatic Dye and Chemical Dispensing (Cotton Inc., 2009)

Economic Data

Investment costs for such systems vary, depending on the number of dyeing machines to be served and the type of the dyes. A report of the European Commission (EC, 2003) provides indicative values for systems handling liquid chemicals (from €260,000 to €350,000), powder dyes (from €285,000 to €800,000) and powder auxiliaries (from €125,000 up to a maximum of €350,000). These figures do not include costs for pipes and conjunctions.

Table 1 presents the range for the investment cost and the payback period of automated preparation and dispensing of chemicals in dyeing houses from a more recent study of the Canadian Industry Program for Energy Conservation (CIPEC, 2007).

Cost savings can be achieved due to the decrease in the use of chemicals and the reduced energy and water consumption (Hasanbeigi, 2010).

Table 1. Cost and Payback Periods of Automated Preparation and Dispensing of Chemicals in Batch Dyeing Systems (CIPEC, 2007)

	Capital Cost	Payback Period (yr)
Automatic Chemical Dispensing System	€100,000 - €650,000	1.3 - 6.2
Automatic Dye Dissolving and Distribution System	€70,000 - €300,000	4 - 5.7
Automatic Bulk Powder Dissolution and Distribution Systems	€55,000 - €450,000	3.8 - 7.5

Environmental Performance

The automatic dye and chemical dispensing machines save almost 15% of water used in wet processing and allow energy saving almost 15% in comparison to other conventional techniques (EBSCO, n.d.).

Maturity and Availability

Fully automatic dispensing systems are most common in laboratories, used for color development and sample preparation. Automatic dispensing systems are used in larger and more modern mills, especially for batch dyeing of yarns and knits.

2.1.3 Plasma Finishing Technology

Description

Plasma finishing technology can be used for the surface treatment (finishing) or the modification of textile materials or products, providing a wide range of functionalities to the end-products. It is essential that this treatment can be applicable to most of textile materials for surface treatment.

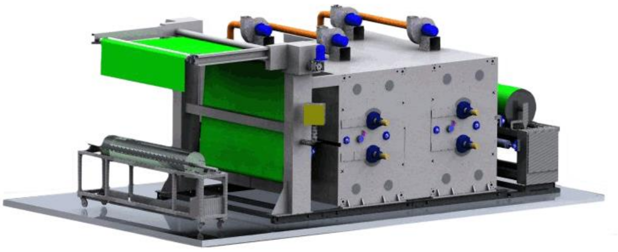

Figure 3. Textile plasma treatment system (Arioli, n.d.)

In addition, it is a dry textile treatment processing without any expenses for effluent treatment. There are many alternatives of plasma finishing technologies that correspond to different applications and materials in the textile industry (Table 2).

Table 2. Various applications of plasma technology (Shah & Shah, 2013)

Application	Material	Treatment
Hydrophilic finish	PP, PET, PE	Oxygen plasma
Hydrophobic finish	Cotton, P-C blend	AiSiloxane plasma
Antistatic finish	Rayon, PET	Plasma consisting of dimethylsilane
Reduced felting	Wool	Oxygen plasma
Crease resistance	Wool, cotton	Nitrogen plasma
Improved capillarity	Wool, cotton	Oxygen plasma
UV protection	Cotton/PET	HMDSO plasma
Flame retardancy	PAN, Cotton, Rayon	Plasma containing phosphorus

Economic Data

This technology has been characterized as too expensive to be adopted in an existing mill. Nevertheless, investment costs should be considered in each case more specifically because the applicability of the plasma finishing depends on the existing processes or structures of the production line (EBSCO, n.d.).

Environmental Performance

The benefits from the application of plasma technology in finishing treatment are the following:

- Better exhaustion of chemicals from the bath;
- Significant reduction of the BOD/COD of effluents;

- Reduction of the wet processing time;
- Reduction of the amount of water used;
- Temperature decrease; and
- Energy saving, due to the elimination of the need for drying or curing.

Maturity and Availability

Plasma technology is an innovative application to the textile industry but “promising” in terms of eco-efficiency. Plasma processing methods that can be used in the textile industry need to be based on atmospheric pressure and low temperature plasma (APLTP). A number of such systems are now being developed commercially (Textile Innovation Knowledge Platform, n.d.).

There are other future technological possibilities related to plasma processing combined with nanotechnology in general, such as the use of cyclodextrins. Cyclodextrins are molecules in three-dimensional structure with a central cavity of hydrophobic nature which can accommodate specific molecules and then release them. At present cyclodextrins for textile finishing are of three types: (a) CD "natural", (b) HP-CD and (c) reactive cyclodextrins. The development of this application is possible, but the technical skills must be improved through scientific and technical industrial trials and verified through realistic expectations.

2.1.4 Cationization for Salt-Free Dyeing

Description

The use of high salt concentration and low reactive dye fixation in order to achieve better dyeing quality in aqueous medium leads to environmental problems related to highly colored effluent with salt content (Chattopadhyay, 2001). Cationization is the chemical modification of cotton in order to produce cationic dyeing sites instead of existing hydroxyl sites, so that cotton can easily attract anionic dyes, eliminating the salt requirement for reactive dyeing and increasing dye color yield. The application of cationic agents requires an additional cycle similar to that for a typical reactive dye (though with fewer rinsing steps), and alkali is required for fixation. Dye selection is critical, as some dyes work better with cationic cotton than others and can be limited by requirements for color, depth of shade, and fastness (especially light-fastness). For safety reasons, the cationic agent should be applied in a closed system (Cotton Inc., 2009).

Economic Data

The investment cost of this technology is less than 200,000€ and can be characterized as expensive. The estimated payback period is 2 years (Cotton Inc., 2009), (EBSCO, 2014).

Environmental Performance

Experiments have shown that dyeing on the treated cotton gave better color strength than the comparable dyeing on untreated cotton by the conventional method, while the color fastness is equal or superior to that of the some dyes on untreated cotton (Montazer et al., 2007).

The application of cationization for salt-free dyeing to textile industries seems to be more sustainable, as it achieves 15% water saving and 15% energy saving, compared to other conventional technologies. It should also be noted that the amount of chemicals required to dye cotton textiles can be potentially reduced by as much as 50% (Cotton Inc., 2009).

Maturity and Availability

This technology has been available for many years and is used commercially in a number of mills for dyeing yarns, knits and garments. However, its implementation is relatively limited due to several reasons, such as the increase of chemical and processing costs due to the low fixation of cationic agents by exhaust methods and the requirement of some modification of existing dyeing processes (Cotton Inc., 2009, EBSCO, n.d.).

2.1.5 Use of Natural Dyes

Description

Natural dyes are dyes or colorants derived from plants, invertebrates, or minerals. Many natural dyes are obtained from plant sources such as roots, berries, bark and leaves. They are also derivatives from wood or other organic sources such as fungi and lichens. The implementation of natural dyes in wet processes, using enzymes reduces production cost and improves control. Moreover, natural dyes are environmentally friendly and can contribute to limit several health impacts caused by the dyed products.

Figure 4. Natural dyes of Mysore market in India (TFOT, n.d.) (Picture by: Kjintransit)

The most common natural dyes are:

- Madder;
- Cutch;
- Cochineal;
- Weld and
- Indigo.

Economic Data

There is a great range of prices of natural dyes, i.e. the indigo dyes cost 3.7-7.4€/kg, while Hill (1997) estimated the average price of natural dyes around 40€/kg. Despite the cost variation, natural dyes are generally considered more expensive than conventional dyes. On the other hand, the production cost could be controlled and reduced in terms of water saving and chemical reduction achieved by the natural dyes.

Environmental Performance

There are many advantages in using natural dyes in the product line which (in many cases) can eliminate the drawbacks of this technique. Natural dyes are environmentally friendly and can give rise to almost any color with the few exceptions (such as fluorescent and electric blues). Furthermore, the water consumption of natural dyes such as indigo can range from 8.3 to 50L/kg production, which is very low compared to other dyeing technologies. These dyes can make textile industries more competitive, by reducing production costs and eliminating the huge expenses of chemical imports.

Maturity and Availability

The technology is relatively mature and readily available on the market, although the research of the optimization of natural dyes is still important and promising for textile industry.

2.1.6 Enzyme Treatment

Description

Enzyme technologies are used widely in most mills, but their most widespread use is in desizing process. The conventional methods of desizing are difficult to control and sometimes could damage the material, whereas using enzymes, the size can be removed without damaging the fibers. Enzymes are also used in pretreatment processes, before dyeing, to improve color quality and minimize the required time, as well as in scouring, bleaching and wet finishing (Cotton Inc., 2009, OECOTEXTILES, n.d.).

Figure 5. Enzymes used in textile processing (OECOTEXTILES, n.d) (Photo from Novozymes)

The technology is applied to all textile forms and in most types of processing equipment, both continuous and batch. Textile industry units have reported savings in water, time, chemicals, and energy, as well as gaining special product feature.

Economic Data

The investment cost of this technology is less than 200,000€ and the payback period is almost 2 years (EBSCO, n.d.).

Environmental Performance

Enzyme treatment in the textile manufacturing process improves the eco-friendly profile of dyeing products. In fact, enzymes contribute significantly to:

- Achieve milder conditions, considering temperature and pH, comparing with the conventional chemicals, which results in lower energy costs (up to 120 kg CO_2 savings per ton of textile produced);

- Water saving – reduction of water usage up to 19,000 liters per ton of textiles bleached (15% reduction can be achieved);
- Energy saving (up to 25%);
- Reduce costs for wastewater treatment;
- Improve the quality of material, because the fiber structure is not damaged;
- Safer working conditions, because chemical treatments are limited during production processes;
- Create an eco-friendly profile, as enzymes are biodegradable (ECOTEXTILES, 2014).

Maturity and Availability

Enzymes have been used in the textile industry since the late 1980s but the industry experience with enzymes has grown rapidly the last 10 years, as the developed enzymes are able to replace chemicals used by mills.

2.1.7 Other Innovative Applications

Electrochemical dyeing processes

Scientific literature is rich in articles on the application of electrochemical techniques for the reduction of vat dyes and indigo. The proposed techniques are indirect reduction techniques that use a mediator consisting of a reversible redox system with the ability to recycle the dye bath. The process is of great interest as it would offer important advantages in the environmental field by reducing sulfur use (sodium dithionite in particular).

The electrochemical dyeing technology enables recycling of dyebaths, thus considerably reducing chemicals, water consumption and effluent output. An already patented technology (DyStar) combines an electric current with a recyclable mediator. It replaces the non-regenerative reducing agents currently used to apply vat and sulfur dyes to textiles, which often prevent recycling of the dyebath and cause contamination of production effluent (DyStar, 2006).

It has already been applied to an industrial process, which uses DyStar Indigo Vat 40% Solution, which allows a cleaner denim production and a reduction of the Sodium Hydrosulfite usage by 60%-70% (DyStar, n.d.)

Phase change materials

Phase change materials (PCM) take advantage of latent heat that can be stored or released from a material over a narrow temperature range. PCM possess the ability to change their state with a certain temperature range. These materials absorb energy during the heating process, as phase change takes place, and release energy to the environment in the phase change range during a reverse cooling process. Insulation effect reached by the PCM depends on temperature and time. Recently, the incorporation of PCM in textiles by coating or encapsulation to make thermo-regulated smart textiles has become the focus of further research.

The spread of technology has been so far rather limited, mainly to products for the sports industry or the military. Currently, the research focuses on new formulations

(PCM dispersions with active content up to 50%), which can be used in the finishing stage that can lend itself to wider applications (instead of chemical fibers loaded with PCM during extrusion). The placing on the market has already taken place, the implementation does not require complex technical skills and growth forecasts are strongly linked to the liking that the final consumers show for the characteristics obtainable (Shin et al, 2005).

Ecotec®

Ecotec is an ecological process of advanced recycling of left-over or excess production material such as cut-off pieces or imperfectly sewn garments produced. The first step is collecting the left-over material which the second step consists of separating the collected material by color, cutting it into pieces, shredding and finally mixing with new fibre. The re-cycled material is ready to go into the spinning process and finally into the machines that produce the Ecotec yarn. The process has been developed by FildiUSA, and is being implemented by Marchi & Fildi Textile Company in Biella.

The Ecotec process reuses left-over material that would be otherwise wasted, leading to

- Elimination of solid waste and reduction of air pollution from waste incineration;
- Reduction of natural resources depletion connected to cotton cultivation; and
- Reduction of pesticides, used for cotton cultivation.

Ecotec reduces the use of natural resources and the energy consumption. Normally, 1kg of cotton requires about 112lt of water and 8,65kWh of electricity. Ecotec allows saving of up to 90% of water and electricity, which is achieved by skipping five conventional production steps. These are all connected to the dyeing, which is the phase that most uses chemicals.

The Ecotec production starts with already coloured material. The yarns pass through the phases of knitting, sewing and finishing before being ready. Ecotec is processed through a conventional production chain, and does not require special technology. Particular attention is only required during the complex blending of left-over material with new fibre. This phase is called darning, and its complexity just requires the experience and skills of specialised personnel in order to ensure high-quality recycled material. The final output is a highly resistant and clean yarn with up to 90% recycled content (EMCC, n.d.).

2.2 Water Supply Chain Technologies

2.2.1 Advanced Oxidation Processes

Description

Textile industry effluents can be characterized as dangerous for receiving waters, due to their high chemical oxygen demand (COD) and total organic carbon (TOC), high amounts of dissolved solids and possibly heavy metals (i.e. Cu, Cr, Ni). The presence of these compounds in the waterways is a major concern, because of their non-biodegradability and potential carcinogenic nature.

Advanced Oxidation Processes (AOPs) are the processes, which are based on the generation of very reactive free radicals, especially hydroxyl radicals, and their use in sufficient quantities to be able to oxidize most of the chemicals present in textile wastewater. The mechanisms of AOPs involve two steps: a) the generation of hydroxyl radicals by the use of UV, UV/O_3, UV/H_2O_2, Fe^{2+}/H_2O_2, TiO_2/H_2O_2, and b) the oxidative reaction of hydroxyl radicals with the dissolved organic pollutants, producing CO_2 and H_2O. AOPs are classified into two categories: a) Non-photochemical oxidation processes, including cavitation, Fenton and Fenton-like process, ozonation at high pH, wet air oxidation, electrochemical oxidation etc., b) Photochemical oxidation processes, including homogeneous (e.g. UV/O_3, UV/H_2O_2, photo-Fenton etc.) and heterogeneous (e.g. photocatalysis) processes (Yonar, 2011).

Economic Data

The technology cost is strongly depended on the flow rate and nature of effluents, as well as on the quality and quantity of reagents. As a result, complete cost analysis of the AOPs is limited in literature, although some representative average costs of the aforementioned processes are given in Table 3. The running costs for the Fenton oxidation process are low, in contrast to the ozonation, which is characterized as expensive.

Table 3. Average operational costs of AOPs (Yonar, 2011)

Process Type	Operational Cost ($/m^3)
Ozonation	4.21-5.35
Fenton Process	0.23-0.59
Fenton-like Process	0.48-0.57
Peroxane (O_3/H_2O_2) Process	5.02-5.85
UV/H_2O_2	1.26-4.56
UV/O_3	6.38-8.68
UV/O_3/H_2O_2	6.54-11.25

The capital costs of an AOP treatment plant include the construction, mechanical, electric and other costs (charges, taxes) and seem to be lower than that of conventional treatment plants, i.e. the capital cost of a conventional treatment system is about 180,000€, while for a Fenton process treatment system is 150,000€ (Yonar, 2011).

Environmental Performance

The AOPs are applied mainly during the decolorization step in wastewater treatment plants. The environmental performance of each one of the above processes is different, as shown in Table 4. According to this, Fenton oxidation process is a very promising technique for the treatment and decolorization of textile effluent, achieving the complete removal of colorants and the removal of COD by 70-80% (Yonar, 2011).

Table 4. Environmental Performance of some AOPs (Vandevivere, Bianchi, & Verstraete, 1998)

Process	Stage	Performance
Fenton oxidation	Pre-treatment	Full decolorization
Ozonation	Post-treatment	Full decolorization; water reuse
Photocatalysis	Post-treatment	Near-complete color removal; detoxification

Maturity and Availability

Advanced Oxidation Processes have been applied extensively, apart from some that are still in pilot-scale. The Fenton oxidation process has been applied in several plants in South Africa. Ozonation is also applied in a full-scale, despite the limitation of aldehydes formation and high cost (Vandevivere et al., 1998).

2.2.2 High -Technology Filtration Systems

Description

Filtration is a conventional and widely used technology for textile wastewater treatment, in the main- or post-treatment stage. The high – technology filtration systems are based on the appropriate use of high–technology (micro, ultra, nano, and reverse) osmosis filters. They are designed for specific fine particles, molecules and ions that must be removed. Applications include ultrafiltration and reverse osmosis for bleaching and scouring process streams; ultrafiltration and evaporation for mercerizing streams; and ultrafiltration and reverse osmosis for dyeing streams (Cotton Inc., 2009).

Figure 6. High -Technology Filtration System **(Cotton Inc., 2009)**

Economic Data

The investment cost for these filtration systems ranges between 200,000 € and 500,000 € and the payback period is 1 to 10 years (Cotton Inc., 2009).

Environmental Performance

The application of such filtration systems in textile wastewater treatment plants is highly effective in terms of environmental performance. Specifically, depending in the technology used, up to 95% of water can be recycled and reuse of salts and heat is also achieved (Cotton Inc., 2009), (Vandevivere, Bianchi, & Verstraete, 1998). Some high – technology filter systems offer self-cleaning capability, to extend the life of the filter (Cotton Inc., 2009).

Maturity and Availability

The technology is considered mature, both technologically and commercially. There is extensive use of filtration systems in regions where water availability is restricted or increasingly threatened, such as in South Africa (Vandevivere, Bianchi, & Verstraete, 1998), (Cotton Inc., 2009).

2.3 Eco-innovation projects for textile industry

Bioprocessing for sustainable production of coloured textiles (BISCOL) is a project co-funded by European Commission, and coordinated by the University of Siena in Italy. It has developed a new bio-dyeing process, based on the ecological optimization of the overall dyeing process cycle, for European textile SMEs which will become more competitive and innovative.

The bioconversion of raw materials into competitive eco-viable final products will be performed through:

- Textile pre-treatment aiming to increase dyeability of textiles;
- Synthesis of bio-dyes using new safe and environmental friendly routes (enzymatic processes);
- Synthesis of new auxiliaries at lower environmental impact; and
- Optimisation of dyeing process reducing energy demand (e.g. lowering temperature and time of treatments).

The initial results have indicated that through the BISCOL dyeing process 50% reduction of the production costs of the whole dyeing process compared to the conventional process (BISCOL, 2014).

3 Innovative technologies Water for Case Study #6: Cogeneration of Thermal Energy and Electricity

3.1 Technology Implementation Objectives

The main environmental problem caused by the operation of the cogeneration plant in the Amsterdam-Rhine canal is the increase in the average temperature of the river due to the large amount of thermal discharges of cooling water, which can cause serious problems to the ecosystem biodiversity. Thus the main focus of technologies to be assessed will be the control of thermal discharges.

Furthermore, another objective should be the increase in the efficiency of thermal energy distribution, which will have a positive impact on the fossil fuels depletion and will contribute to the reduction of greenhouse gas emissions.

3.2 Production Chain Technologies

3.2.1 Aquifer Thermal Energy Storage (ATES)

Description

The heat demand in domestic areas is defined by the required energy for heating spaces and rooms and by the required energy for hot water, mainly for bath and shower. Generally, this heat demand is produced by in-house gas-based units that deliver water up to 90ºC. The heat is delivered by high temperature radiators in the buildings. A sustainable alternative for heating spaces is the application of aquifer thermal energy storage in combination with heat pumps. Water in the aquifers is pumped up to the surface and heated with heat pumps that are fed with an external heat source. The water is pumped back in the aquifer and remains there until the heat demand creates the possibility to make use of the stored heat.

If the water is heated up to 45ºC during summer and fed into the aquifer, it is possible to provide direct heating of spaces without heat pumps. In industrial areas, a large amount of residual heat is available continuously and at different temperatures. It is often discharged into nearby surface water or into the air. In combination with MTS (Mid Temperature Storage) the residual heat can be adequately used as a source for heating spaces and buildings. The usage of residual heat for heating spaces by using MTS is shown in the schemes below. The first scheme (Figure 7) shows the summer situation, in which the residual heat is used to “charge” the MTS-well, as well as to provide required hot water directly in the buildings.

The second scheme (Figure 8) shows the winter situation, when the heat demand is much larger; the residual heat from the charged well is added to the residual heat that is actually produced and both are used to match the heat demand of the buildings.

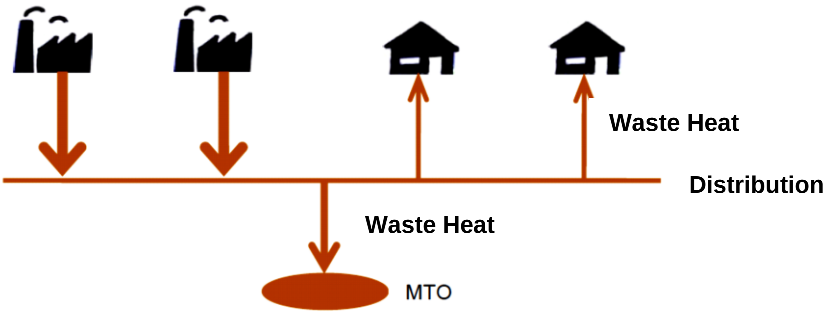

Figure 7. Summer situation

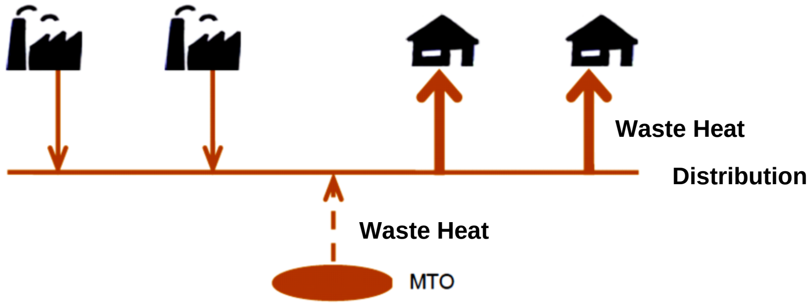

Figure 8. Winter situation

In order to get hot tap water (65ºC) it is necessary to add an additional system. A sustainable system that meets the requirements is a heat pump boiler combined with a hot fill. The water is pre-heated with the residual heat, additionally treated with the heat pump and stored in the hot fill.

Economic Data

The data for this technology are taken from a recently designed MTS-system for an industrial area near Rotterdam (Woning et al., 2012).

Table 5. Investment Costs

Component	Cost
Collective heating unit	100 €/kWh
Individual heating unit	3,000 €/house
Collective heat pump	200 €/kWh
HP-boiler	3,500 €/house
Distribution net outside	400 €/apartment
Distribution net outside	400 €/house
Distribution net inside	1,600 €/apartment
Main distribution pipe	750 €/m
Mounting kit 2-in/out	1,000 €/set
Mounting kit 4-in/out	600 €/set

Calculations of the payback period, in comparison with conventional domestic heating systems, point to 25-30 years, in the case that the heat source is at a distance of only 1 km. Since the distance between heat source and demands is an important factor in the investment cost, these payback times can be considered minimal.

Table 6. Planned Investment Costs

Component	Cost
HP-boiler	3,500,000 €
Ground Water System	380,000 €
Civil Engineering	25,000 €
Main distribution net	1,875,000 €
Distribution outside apartments	800,000 €
Distribution outside	2,200,000 €
Distribution net inside	50,000 €
Mounting kits	1,000,000 €
Permitting costs	10,000 €
Design and Advising costs	100,000 €

Table 7. Operational Costs

Component	Cost
Gas usage (variable, individual)	0.48 €/m^3
Gas usage (variable, collective)	0.46 €/m^3
Electricity usage (variable, individual)	0.18 €/kWh
Electricity usage (variable, collective)	0.10 €/kWh
Maintenance demand side (domestic)	3.5% of total investment costs
Maintenance supply side (industry)	2.0% of total investment costs
Maintanace transport (distribution)	1.0% of total investment costs

Table 8. Planned Operational Costs

Component	Cost
HP-boiler	100,000 €
Ground Water System	9,000 €
Distribution net	27,000 €
Monitoring (permit requirement)	10,000 €
Maintenance	147,000 €

Environmental Performance

The environmental performance of ATES is related to two aspects. Firstly, the use of otherwise wasted heat minimizes the use of natural gas or fossil fuels in local installations. This reduces the generation of CO_2 emissions and the depletion of resources. In addition, the thermal waste at the power plant location is reduced, thus also reducing the potential ecosystem damage in the receiving water body. Secondly, ATES can be used as a heat buffer. Generally speaking, this allows for lower peak capacities for heat generation. This also helps reducing fossil fuel consumption at instances of peak demand which often lead to inefficient generation conditions. On the other hand, the (in-) efficiency of 50-75% of using ATES for storage will cause a substantial energy loss and the transportation losses increase with distance. As a result the environmental performance depends on the local conditions such as distance between source and demands, and the storage efficiency attainable in the area. The MTS type of storage delivers up to 65% reduction of CO_2 emissions compared to the conventional system.

Table 9. Planned Operational Costs

	Groundwater System - Summer	Groundwater System - Winter
Charging power	1,740 kWh	
Heat storage	4,071 MWh	
Heating power		1,160 kWh
Heat supply		2,169 MWh
Maximum flow	100 m^3/h	100 m^3/h
Water temperature	30 - 45ºC	30 - 40ºC
Efficiency	50 - 75%	50 - 75%

Maturity and Availability

Using the underground to store thermal energy at elevated temperatures is not widely applied. As a first and very important obstacle, it will be very difficult to achieve an economically feasible design for an ATES system, as is clear from the above mentioned economic data. Technically, building the system should not be a problem. But substantial research is required on the build-up and the properties of the underground, before being able to design the system. Furthermore, there are many obstacles in governmental regulations to overcome before such a system can be implemented.

Evaluation of Aquifer Thermal Energy Storage

Storing thermal energy underground is an attractive idea because it solves a major problem in energy systems: storage. Storing thermal energy in substantial amounts would increase the eco-efficiency of energy systems. Mismatches between generation and demand, a major problem when centrally generating heat and power, could be treated much more efficiently. It would increase the eco-efficiency both at the environmental side by reducing CO_2 emissions and at the economic side by utilizing thermal energy otherwise wasted in the cooling water. Unfortunately, ATES in the present form is not the general solution to the problem and could be an option only in special situations, when the thermal source is very close to thermal demand.

3.2.2 Combined In-house Heat-Power production (HRe unit or Micro CHP)

Description

An HRe, or Micro CHP unit, is an in-house gas combustion unit that produces heat and electricity. Currently the best developed HRe units use a Stirling gas engine.

After a considerable development and testing period, they are now commercially available and introduction projects, sometimes with governmental subsidies, are being launched. A second technique used in domestic HRe units is based on a Rankine Cycle. Such units are also on the edge of market introduction. Other CHP units use a gas turbine, a steam engine or make use of fuel cells. These are not (yet) suitable or commercially available for domestic use, and have not been reviewed here. A domestic HRe unit has a heat-power ratio that suits the energy demand in houses well. Arranged in a cascade they can also be applied in offices, restaurants and public buildings. It is expected that the total Micro CHP power production will rise towards several hundreds of MW per year in the Netherlands.

Figure 9. Micro CHP boiler (Wisselo, n.d.)

The available HRe units are designed to meet thermal demand, and the electricity is a by-product. The produced electricity can be used directly, or, in case electricity demand is smaller than the supply from the HRe unit, the electricity is fed into the electricity grid and will generate revenues. The unit uses a thermal buffer to meet peak heat demand.

If production is based on the electricity demand, the excess heat can be stored in the well isolated heat buffer. However, the possibility to feed excess thermal energy into a thermal distribution network would require large investments in the network infrastructure and connections, and would also require adaptation of the financial accounting. Such an option has not been examined, and in the Case Study Analysis it is assumed that the production in an HR or HRe unit is purely based on thermal demand. The installation of an HRe unit requires connection to the electricity grid and to the network of gas supply, or individual gas supply tanks.

Figure 10. Stirling engine

Economic Data

The investment cost of this technology is 11,000 €. The operational costs are 0.65€/m^3 gas and the avoided cost from electricity production is 0.22€/kWh.

A recent study in Belgium (Six & Dexters, 2009) estimated a unit price of 5,000 € (system cost of 7,100 €) as the maximum for economic viability in the long term. For economic viability a unit price of 3,500 € (system price of 5,500 €) is required. Current prices are much higher and introduction programs are a necessity to reach a critical mass of demand. Only at a much larger scale of production can unit prices drop enough to reach economic viability.

Table 10. Expected annual costs for an HRe unit

Annual Costs	
Gas	1,000 €
Electricity	350 € up to -500 €
Maintenance	70 €

Another barrier is that newly built houses are insulated to an extent that the thermal demand has dropped considerably. As a result, the ratio of electricity demand to thermal demand increases, requiring different specifications of the HRe unit. Unless the unit price drops to much lower levels, separate installations for generating electricity (Photovoltaic panels) and generating heat, mainly for hot water, might be a more attractive alternative. An important factor in the economic viability is the electricity price, since the electricity production must compensate for the higher investment costs by avoiding buying electricity and/or selling electricity to the grid. So, both dropping electricity prices – not unlikely in the future, if local generation and smart grid management get off the ground - and energy saving measures can negatively influence the economic viability.

Environmental Performance

The benefit of HRe units for the environment is that the heat generated during power production is utilized for house warming and hot water production. This avoids the emission of CO_2 to the atmosphere for the amount of thermal energy that would otherwise be wasted in the cooling water. The calculation of how much CO_2 is avoided, compared to the current situation, depends on various assumptions, such as the type of electricity production technology (wind turbine or hydro turbine, power plants fuelled by biomass, nuclear, gas, coal or brown coal). In the Belgian study the range is between 246 and 1,061 kg CO_2 per household. This is a reduction of 5 - 17% compared to the current HR systems.

Technical Specifications			
Electricity production	1	kWh	(per unit)
Electricity production	2,450	kWh/year	(per household)
Heat production	25	kWh	
Environmental Parameters			
Gas Usage HR Unit (heat)	1,650	m^3/year	(per household)
Gas Usage HRe Unit (CHP)	1,892	m^3/year	(per household)
Reduction of CO_2 emissions	850	kg/year	(per household)
Parameters Households			
Gas usage	1,652	m^3/house (average Dutch households)	
Heating spaces	1,212	m^3 (75%)	
Tap water	375	m^3	
Cooking	65	m^3	
Electricity usage	3,350	kWh/year	

Maturity and Availability

The introduction of commercial domestic HRe units on the market is only recent. Test programs and experiments in real conditions have been performed. An introduction program has started in the province of Gelderland (NL), offering a subsidy from government. At least four manufacturers (Intergas, Nefit, Remeha, Vaillant) produce HRe units for the domestic market.

Evaluation of Combined In-house Heat-Power production

HRe units seem to be ready for the domestic market, given the commercial availability and various manufacturers of the units. The producers often advertise a payback period of about 5 years, but the returns on the electricity bills seem rather unrealistic. But even if the payback period is doubled, HRe units seem to be a viable alternative for conventional HR central warming units. Nevertheless, there are several considerations questioning this positive message. Heating systems are bought for the next 15 - 20 years and preferably a new system should remain competitive during that period. HRe units are only suitable above a certain minimal thermal demand, estimated at about 2,000 m^3 gas consumption. Since the HRe units are designed to meet thermal demand, lower gas usage results in lower electricity production. As a result, the income generation by electricity production provides insufficient compensation for the higher investment costs.

One possible drawback is that there is no experience on how these units will perform with ageing. The units are considerably more complex than standard central heating units, due to the electricity generation part and the coupling between the two. Maintenance and repair costs will be higher than for the much simpler conventional installations. Price fluctuations for electricity and gas determine the economic performance of the system. In the scenario that the expected increase in gas price is not counterbalanced by a similar increase of the electricity price -for instance as a result of a successful transition to power generation from renewable resources - the higher gas use of HRe compared to conventional, will not be compensated for. A similar argument holds for individual insulation measures. If the gas consumption is lowered, the payback period is prolonged.

When considering HRe from a meso-level point of view, there is an additional point to discuss. The effect of installing domestic HRe units is that part of the power generation is transferred to the households. The heat produced in the houses is utilized, while for the power plant the surplus heat is wasted with the cooling water. However the energy demand of a household is dynamic in time. The greater part of thermal energy demand is for house warming, which is not a year round demand. In the Netherlands, this demand exists during 4 - 6 months, only. Demand for hot water continues throughout the year, but is much smaller. So, the benefit of domestic heat generation only applies for part of the year. When there is no heat demand in the house, the electricity demand is fulfilled from the grid, yielding waste heat. Although a reduction of CO_2 exhaust of 5-17% is substantial, this environmental benefit is created only during a part of the year, and produces waste heat during the rest of the year. A combination of photovoltaic panels and conventional heating might do better on meso-level scale, because in that case the domestic power generation would not create waste heat.

3.2.3 Heat distribution network

Description

Combined Heat Power is generally described as an improvement of a power plant in the sense that the heat produced is utilized, at least in part, and no longer discharged as waste heat with the cooling water. Although attractive, this view is too simplified.

A CHP plant is a system converting the energy content of the fuel into heat and power, while generating CO_2 emissions, with the use of water for cooling. Heat and power production are combined, but not independent. Maximizing power production requires the lowest possible temperature at the condensing site of the generator. As a result, tapping water at elevated temperatures has a reducing effect on the efficiency of the power generation itself. Tapping heat is not free.

The utilisation of heat, whether at high or low temperature, requires a transportation and distribution network, from which consumers can satisfy their heat demand through heat exchange facilities. The goal of a distribution network is to transfer waste heat discharged with the cooling water into utilisable heat for consumers. This way waste is converted into value and the waste heat replaces the locally produced thermal energy from burning fossil fuels. This technique affects both terms of the ratio building the eco-efficiency indicator and has a double positive effect on its value.

The technique reaches its maximum efficiency if the total amount of thermal energy transferred through the distribution network is used. Two aspects are important: the *temperature* at which the thermal energy is offered in the distribution network, and the *use time,* i.e. the time proportion of a year during which the thermal energy is consumed. The higher the temperature, the higher the economic value will be, since heat can be applied to more processes. The importance of use time is apparent from the application for domestic heat supply. Domestic Heat Demand is not constant in time, varying over the day, and with the seasons. In practice, peak heat demand for domestic heat only occurs a few days per year and Heat Demand for house warming only exists during 30 - 50% of the year. During the rest of the year (the non-profitable time window) most of the produced heat remains waste heat to be discharged with the cooling water. These two points made it relevant to explore the application of a heat transportation and distribution network as an eco-efficiency enhancing technique, a bit wider than finding a profitable destination for low temperature heat.

Tapping water at higher temperatures reduces the useful electrical power somewhat (green solid line in Figure 11). The gain of transferring Heat loss in *useful* heat, however, increases at a much higher rate and more than compensates for this loss of power generation efficiency. As a result, the whole system becomes more efficient, energy wise. The amount of useful heat helps in eliminating a similar amount of local thermal energy generation, which contributes to the overall decrease of CO_2 exhaust and mineral depletion. In the economic sense, selling the useful heat contributes to value creation. The economic value of heat delivered increases with temperature. Preliminary calculations show that there is a serious business case in this total system approach.

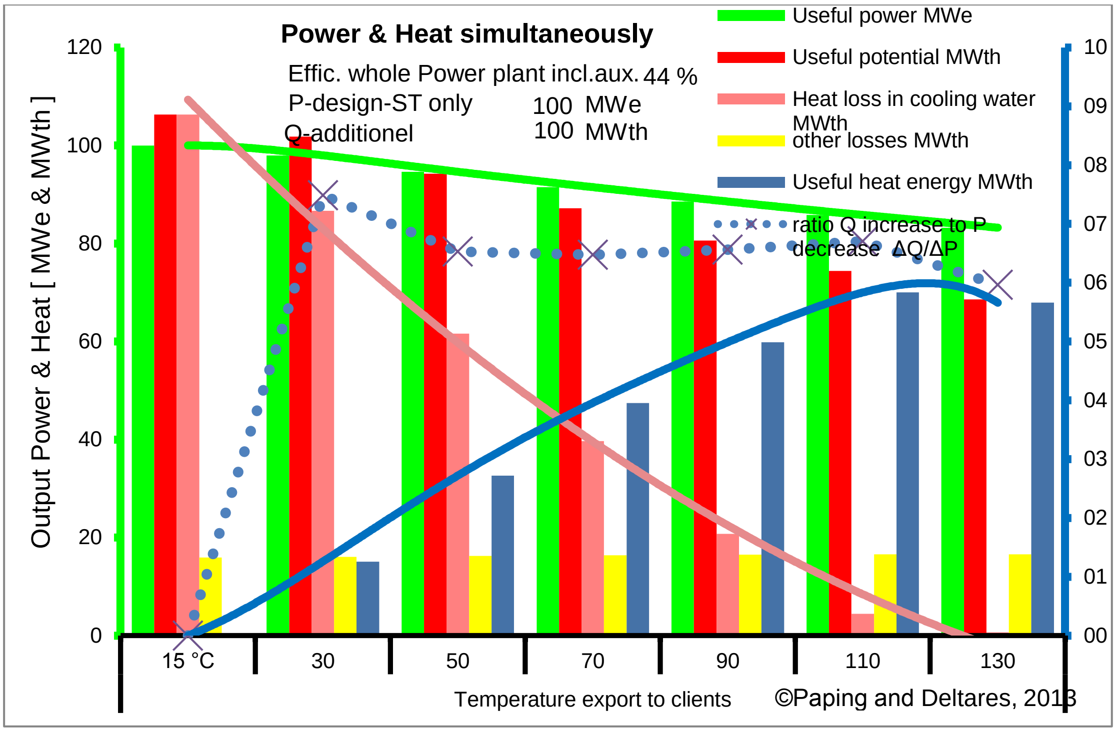

Figure 11. Analysis of the effects of thermal energy distribution at different temperatures on power generation efficiency and useful thermal energy

Economic Data

The focus for the economic side of eco-efficiency is on converting generated thermal energy into *utilizable* energy. The more heat is utilizable, the more value is created and the less environmental impact is produced. The low efficiency of the electricity generation process is then easily compensated for.

Value in the system is created as a result of consumption of thermal energy by households and industries. For households the equal costs principle holds, i.e. the price for thermal energy from a domestic heat distribution system should not be higher than the price for local energy generation from gas. This is a governmental rule to protect the consumers against the possible negative consequences of being connected to a monopolist provider. This sets the price maximum to 0.07 €/kWh, equivalent to 0.65 €/m^3 gas, although the accounting system can use a different distribution over fixed and flexible, consumption dependent costs. In practice this price limit restricts the development of heat distribution networks.

It is extremely expensive to set up a distribution network. The transportation pipe from the power plant to where the distribution network begins, is affordable if the pipe can be planned through a more or less bare trajectory. The majority of the cost lies in digging up and re-paving all streets in the neighbourhoods and connecting all houses to the network. These costs are very difficult to estimate because the local conditions are so important, such as crossing other infrastructural networks, traffic situations, etc. An average replacement cost is estimated at €400/m (price level 2004). For large diameter pipes this may come up to 3,000 €/m. The connection costs are estimated at 75 € per house. With a mean length of distribution pipe per house of about 16 m, a mean investment per house 16 × 400 +75 = 6,475 € can be calculated, as a rough estimate (Grontmij Nederland B.V., 2005).

In addition, it is important that all houses are connected to the distribution network. Any connected house increases the average price per connection. As a conclusion, it is often said that building a network in an existing neighbourhood is not feasible. The creation of such a network is an option only in new neighbourhoods. However, newly built neighbourhoods create a difficult business model because the heat demand of modern houses is low as a result of modern insulation measures.

The opportunities in industrial areas are much better. The number of connections is smaller due to the larger average heat demand of industrial clients, and the possibilities to earn back the installation costs in reasonable time are better because industries may be expected to have a more constant consumption profile over the year (higher use time). From an economic point of view, the challenge is to develop industrial areas in the neighbourhood of a power plant and to attract consumers whose yearly and daily consumption profiles fit well with the thermal energy generation profile of the power plant.

Environmental Performance

In the cogeneration system the main relevant Environmental Impact (EI) indicators are climate change, thermal pollution and fossil fuel depletion. Since the thermal pollution by waste heat discharge is bound by permits that prevent ecosystem impacts (CIW, 2004), the effects of thermal pollution cannot be determined in the real situation. Climate Change and Fossil Fuel depletion can be calculated (see deliverable 4.2). Both will decrease as a result of thermal energy distribution. The impact of this technology depends on the thermal energy consumers. Both the quantity of heat consumed and their use time are important. The ideal user with greatest environmental impact would be one that also consumes CO_2, such as greenhouse farms. Greenhouses would take up more CO_2 than what is equivalent to the avoided local thermal energy generation. On the other hand, the heat demand of greenhouses has a seasonal pattern that differs from the heat generation profile throughout the year. The environmental benefits will be lower during part of the year. In practice, the challenge is to create a combination of thermal energy consumers, whose day and year consumption profiles together closely follow the thermal energy generation profile of the power plant.

Maturity and Availability

Technically heat distribution networks are mature, installation capacity is available and distribution of thermal energy occurs at various locations. The main barriers for application are financial and organisational. Distribution networks are very expensive and require support from many parties before installation is possible. The investment horizon is very long term (30 - 40 years, at minimum) and long term stable governmental conditions are required to attract investors. In addition, many permits are required from local and higher governments. Creating a distribution network starts with a complex and demanding process. Moreover, financial feasibility is difficult to achieve. Feasibility is increased by smart planning of the devilment of industrial sites, and attracting a mixture of companies with a good combination of demand profiles. Another possible development direction would be to create distribution networks as an (governmental) infrastructural service, like transportation or sewage networks, allowing many sources and users to connect, and to have then operated by an independent organisation.

Evaluation of Heat distribution network

Heat distribution networks have a high potential for eco-efficiency improvement of power generation. The leverage is very high because making waste heat profitable affects both terms of the eco-efficiency indicator towards higher values. Implementation of the measure is complicated as a result of the many parties involved and the high investments required.

3.3 Water Supply Chain Technologies

3.3.1 Smart Cooling by small bubble screens

Description

Research into the physics of applying small bubble screens to deal with salinity intrusion problems, revealed the potential of using those for smart cooling. In smart cooling small bubble screens are applied to enhance the exchange of heat between water and air. Loss of heat from surface water is mainly caused by evaporation. Bubble screens increase enormously and very rapidly the surface area of the water-air interface, without the surface film that develops with time at interfaces. A small 50 l/s bubble screen, consuming only 10 kW of compressor power, creates 36 ha/hr of new exchange interface. Experimentally, it has been shown that heat exchange from air to water is doubled at interfaces without a surface film.

Small bubble screens, strategically positioned in the heat discharge stream, could strongly enhance the heat loss from the discharge to the atmosphere. This would decrease the environmental burden for the receiving river, lake or stream. Either the discharge temperature could be lowered, keeping the discharge volume the same, or the discharge volume could be lowered keeping the temperature increased to the allowed limit in the discharge permit. In any case the near field influence will be reduced at the discharge location.

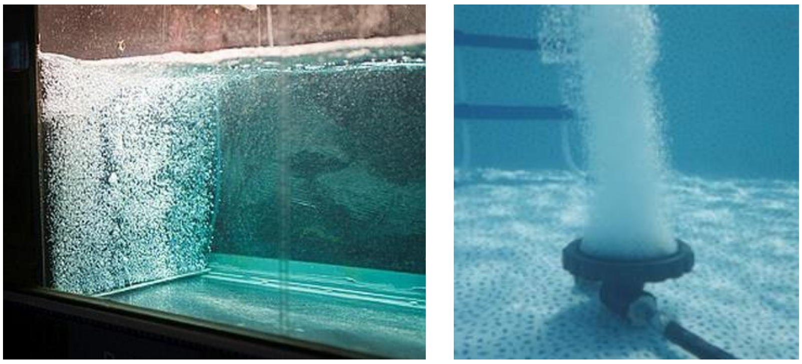

Figure 12. Air curtain of bubbles (Deltares, n.d.)

This technique could also be very helpful in situations with a shortage of cooling capacity, enlarging the potential cooling capacity without increasing environmental concern. This could be helpful in situations where several power plants are present along a river.

Economic Data

The investment cost of this technology is low. The operation and maintenance costs depend on the operational settings, which must be carefully set. Incorrect settings may enhance energy consumption dramatically and as a result may cause increase of the cost.

Environmental Performance

An additional advantage of small bubble screens is that they effectively suppress the development of floating layers of blooming cyanobacteria (blue green algae). The increased oxygen content of the water may yield a water quality improvement, e.g. by reducing the sediment water exchange of phosphates, often a limiting nutrient for algal growth. Of course, increased evaporation will have negative effect on the water balance, and might lead to foggy conditions.

Maturity and Availability

Application of bubble curtains is quite common. The technique has been used at the cooling water inlets of power plants to divert fish and in aeration facilities in sewage treatment plants (Woning et al., 2012). Experimental application in a sluice to reduce salt water intrusion is under way. Technically bubble curtains are mature. Operational requirements minimizing energy consumption depend on local conditions and must be assessed locally.

Evaluation of small bubble screens

The application of small bubble screens could be helpful to reduce the near field effects of thermal discharge. However, it also facilitates the discharge of more heat. Since effects of thermal discharge are relatively small if discharge permits are well suited to the local situation, it would make much more sense to reduce the amount of waste heat. This restricts application of bubble screens as a technique to increase eco-efficiency to situations with a water shortage and / or those where successive power plants along a water body show interaction of discharged heat of the upstream plant on the water intake of the downstream one.

3.3.2 Modified Travelling Water Screens

Description

Modified travelling water screens fall into one of four categories of intake technologies, namely into the collection systems, which actively collect fish for their return to a safe release location. Conventional travelling water screens have been altered to incorporate modifications that improve survival of fish. More specifically, fish mortality is minimized through screen impingement and spraywash removal. The screen baskets are equipped with a water filled lifting bucket that safely contains collected organisms. Once collected, the fish are released to a safe location (Taft & Cook, 2005).

Figure 13. Modified Travelling Water Screens **(Taft N. et al., 2003)**

Economic Data

The cost of the application of this technology may be affected by a variety of factors, including biological, geotechnical, climatic factors etc. For example, the species present near the intake can influence the design of a modified travelling screen retrofit. The hardware and construction activities increase the overall cost. The relative hardiness of the organisms could also affect the cost of installation, because there would be a requirement for reduction in through-screen velocity, which would increase the investment cost. The construction cost of coarse mesh ristroph screens is about $6,000,000 and the operation and maintenance costs are approximately $500,000 (Taft & Cook, 2005).

Environmental Performance

This technology seems to be effective in terms of environmental performance. The reported survival rates for this installation are among the highest for any traveling screen system (Taft & Cook, 2005).

Maturity and Availability

Ristroph screens have been installed at a number of power plants (e.g. Salem Generating Station in the Delaware River) and as a result, the studied technology can be characterized as mature. Although improvements to the ristroph screen design have been made since late 1980s and early 1990s, modified travelling water screens continue to be an available technology that reduce fish losses (Taft & Cook, 2005).

4 Innovative Technologies for the Dairy Industry

4.1 Technology Implementation Objectives

The study of technology implementation is focused around the actor Arla HOCO, whose processes had the biggest contribution to the system's environmental impacts. Emphasis will be given on the processes with higher water and energy consumption, as these were identified by the relevant actor.

The processes with the higher water consumption are:

- Rinse process in casein-plant,
- CIP cleaning in place,
- Standardization/diafiltration of products,

whereas the processes with the higher energy consumption are:

- Spray drying for water evaporation (the bigger consumer),
- Cooling water and ice water production,
- Pasteurization,
- High pressure pumping (i.e. for membrane filtration),
- Compressed air (process air and sterile air),
- Transportation.

4.2 Production chain technologies

4.2.1 Condensation of vapor from spray towers

Description

Large amounts of water evaporate in the spray dryers – water also containing significant f bound energy. The total amount is approximately 3 kg of water per kg of product. This water comprises the most significant opportunity for separation of a very clean water stream for reuse.

The condensation could be achieved by using the vapor used to preheat the drying air for the spray towers. This could be done in an air-air heat exchanger or in air-liquid-air double heat exchanger – with a recirculating medium in between.

Economic Data

The investment for this solution will be high but can be paid back mainly through savings in natural gas consumption.

Environmental Performance

Direct savings in natural gas consumption will be achieved, and significant amounts of water will be recovered and could potentially be reused. There will be an increase in electricity consumption to drive fans and pumps for this solution - however, a side effect may be better air pollution control of dust from the spray dryers.

Maturity and Availability

Systems are available on the market place – but application in industry is not widespread.

4.2.2 Recovery of CIP baths

Description

Cleaning-In-Place is essential in HOCO's production for keeping a high hygienic quality of production equipment. A typical CIP sequence could be:

1. Product recovery,
2. Pre-rinse,
3. Alkaline solution wash,
4. Intermediate Rinse,
5. Acid solution wash,
6. Final Rinse.

The chemical baths are of interest here, as these contain water as well as chemicals and heat that can be recovered by installation of a nano-filtration membrane in a bypass on the chemical CIP tanks. Water and chemicals will be able to pass through the membrane while contaminants in the CIP baths are rejected as wastewater. In this way it is possible to extend the lifetime of the chemical CIP solutions and as such save water, chemicals and energy.

Economic Data

The system may be expensive as it requires new piping, pumps, instrumentation and technologies.

Environmental Performance

Savings in water, chemicals and heat (natural gas) may be achieved through this solution.

Maturity and Availability

The technologies are available on the market – but only applied to a limited extent in industry.

4.3 Water Supply Chain Technologies

A number of technology implementations have been under consideration, but only one technology has been evaluated in-depth, the decentralized anaerobic pre-treatment of the wastewater from Arla HOCO.

The reason for selection of this scenario is that changes in the composition of the wastewater will influence actors downstream of Arla HOCO in the Wastewater Treatment and Energy Production stages. Actors in the Water Supply and Transport stages are not influenced by this scenario – however, if the liquid waste products were to be treated in Arla HOCO's own anaerobic treatment system, then this scenario would also influence actors in the Transport stage.

A number of other scenarios will be evaluated in later stages of the project once more data on specific sub-processes within Arla HOCO are available.

4.3.1 Anaerobic pre-treatment of wastewater

Description

Anaerobic digestion (AD) is a technology that can transform organic waste products into energy through production of biogas (methane), which can be used to substitute natural gas consumption in the dairy – or be used for power and heat production.

Anaerobic Digestion for pre-treatment of wastewater from Arla HOCO aims to reduce the organic load on the municipal WWTP, while producing energy instead of using energy for aeration requirements in the WWTP.

Economic Data

Anaerobic digestion on dairy wastewater is a well-established technology with several suppliers of comparable technologies. As such it is possible to receive reliable quotations from suppliers on investment as well as operational costs of an AD system.

Environmental Performance

The AD system converts organic substances in the dairy wastewater (mainly fats, proteins and sugars) into mainly methane and carbon dioxide (biogas). The biogas can be burned and used to substitute natural gas or produce electricity and heat, and the methane will be converted to CO_2.

The energy consumption of the downstream WWTP will be reduced – as will the energy production from sludge treatment following the WWTP. However, the reduced biogas production from sludge treatment is more than compensated from the energy production in the pre-treatment stage.

Maturity and Availability

The AD technology is fully mature and available on the market.

Evaluation of anaerobic treatment implemented in Arla HOCO

The implementation of an AD pre-treatment system on the wastewater from Arla HOCO has been evaluated using the EcoWater approach.

The following impacts on different actors have been identified:

- Energy production at Arla HOCO to substitute use of natural gas – resulting in reduced fossil fuel depletion and CO_2 emissions,
- Reduced organic load on the downstream WWTP – with reduced fossil fuel depletion and CO_2 emissions,
- Reduced biogas production in the Energy production stage – resulting in higher CO_2 emissions (from burning fossil fuels to substitute the biogas) and fossil fuel depletion.

In the case of economic evaluation of a system for Arla HOCO, a proprietary standard design and costing model obtained from a supplier of AD systems has been used to estimate investment costs, operational costs, treatment efficiency and energy production of the AD system.

Based on this approach the following EVAT analysis has been carried out showing difference to the baseline study (Table 11).

Table 11. EVAT analysis of the AD pre-treatment system relative to the baseline study

EVAT				
Stage	Annual Equivalent Investment Cost	Annual O&M Cost (€/yr)	Annual Gross Income (€/yr)	Net Cash Flow (€/yr)
Water Supply		**€ -**	**€ -**	**€ -**
-Power		€ -		
Dairy Operations	**€ 168.918,92**	**€ -226.073,43**	**€ -**	**€ 57.154,51**
- Power		€ -		
-Water supply		€ -		
- Natural Gas		€ -226.073,43		
-Wastewater		€ -		
- Raw milk		€ -		
- Sodium Chloride		€ -		
- Other Chemicals		€ -		
-Transport milk		€ -		
- Transport waste		€ -		
- Depreciation 20y	€ 168.918,92			
Wastewater Treatment		**€ -29.351,35**	**€ -**	**€ 29.351,35**
-Power		€ -29.351,35		
- Chemicals		€ -		
Transport		**€ -**	**€ -**	**€ -**
-Diesel		€ -		
TOTAL	**€ 168.918,92**	**€ -255.424,78**	**€ -**	**€ 86.505,86**

The analysis shows that when considering the investment with a 20 year linear depreciation, a positive net cash flow in the Dairy as well as Wastewater treatment stages is observed – while no influence is observed in the Water Supply and Transportation stages. It should be noted that as for the baseline study, the Energy production stage is excluded due to lack of data. However, in fact a small negative net cash flow would be observed in the Energy Production stage due to reduced biogas production.

4.3.2 Membrane bio-reactor with polishing and disinfection

Description

The HOCO production process utilizes different degrees of membrane filters to separate and concentrate valuable products in the milk. Reverse Osmosis (RO) filters are used as a final step in this process to separate and concentrate different products. The permeation from the RO filters is a high quality water stream, however with some small molecular organic and nitrogen compounds still remaining – such as urea. The challenge is that these substances cause the otherwise clean water to be highly microbiologically unstable.

These compounds are very difficult to separate by physicochemical processes and the most efficient way to remove these compounds is by biological treatment. Followed by proper polishing technologies and disinfection these water streams reach a quality beyond drinking water standards – e.g. well known from applications such as NEWater production in Singapore based on a process train with aerobic biological treatment, ultrafiltration, reverse osmosis, UV disinfection and chloramine dosage. It may be beneficial to integrate the aerobic process and ultrafiltration in a membrane bioreactor (MBR).

Economic Data

The main uncertainty factor is whether special sanitary materials and equipment will also need to be used for this application in order to maintain sufficiently high hygienic quality, ease of cleaning and regulatory approval for reuse in food production. Such requirements may significantly increase capital costs of the equipment.

Environmental Performance

Based on the very clean water stream amounts of biological solids will be minimal and can probably be discharged with the wastewater streams. Approximately 25% of the water treated will be disposed as wastewater while 75% can be reused. Power consumption will be in the order of 1-2 kWh/m^3. If chloramine dosage is required, consumption of chlorine will take place.

Maturity and Availability

The technology is relatively mature and readily available on the market.

5 Innovative Technologies for the Automotive Industry

5.1 Technology Implementation Objectives

The study of technology implementation is focused around the actor Volvo Trucks. In addition to being the only actor in the water use stage of the system, they are also an actor within the water supply chain, due to their own water abstraction and treatment of municipal water to purified water for processes. The water use stage is the environmentally weakest stage of the system, with its large energy consumption and emission of pollutants to wastewater, and where implementation of new technology can result in large environmental improvements. Figure 14 shows an overview of the modelled system. The processes where introduction of new technologies will be studied are shadowed. Likely improvements due to new technology in those processes are reduced energy use, reduced water use, less pollution to wastewater. Such improvements are expected to have a positive effect in other parts of the system as well, thus making the whole system better as a result of the technology implementation.

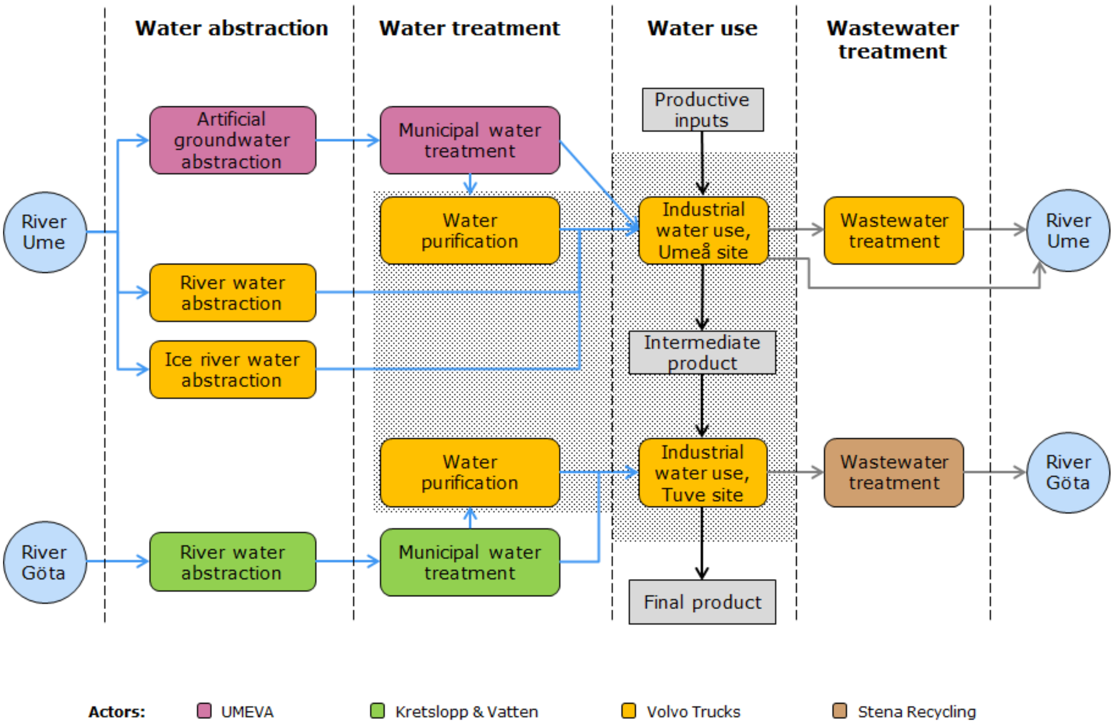

Figure 14. Overview of the CS8 system. The shadowed area indicates where introduction of new technologies will be studied.

5.2 Production Chain Technologies

For the automotive industry, the specific objectives of implementation of innovative technologies in the production chain are:

- Resource efficiency (saving energy, water and use of scarce elements),
- Reduction of hazardous waste (sludge with high metal content),

- Reduction of pollutants in the wastewater (e.g. P, Ni and Zn),
- Reduced operating costs (as a result of the first two bullets).

5.2.1 Silane-based metal surface treatment

Description

A silane based surface treatment can be used as replacement of zinc-, manganese- and iron-phosphating and will provide paint bonding and corrosion protection. This technology has been used successfully in a variety of industries for several years. In terms of quality, it is comparable to the zinc phosphating process. The process does not need activation or passivation and has multi-metal capability.

The chemicals used with this technology are free of the metals Zn and Ni and the limited element P. Instead, silicon and zirconium are the active elements in chemicals. The technology operates at room temperature and with proven less water use than traditional phosphating surface treatment.

In the system of CS8 traditional zinc-phosphating is used at both of the modelled Volvo Trucks production sites. Silane-based technology can primarily be evaluated as new technology for Volvo trucks, Gothenburg, from where there are already test results available. The process outline at the Umeå site differs from that in Gothenburg so the real test results are not directly applicable, but a theoretical evaluation of system performance due to implementation of silane-based technology in Umeå can still be performed.

Economic Data

Investment cost for a silane line is lower than conventional phosphating lines. When replacing an existing traditional phosphating line, it can be possible to re-use and re-configure much of the current process infrastructure for the new technology (e.g. tanks, pipes and pumps). A silane based surface treatment results in lower process costs and higher productivity. Silane processing works at ambient temperature. There is no additional cost for activation, passivation or heating of the bath, with energy savings up to 25%, water savings up to 60% and waste reduction up to 80%.

In the system of CS8, technology uptake and costs of silane-based metal surface treatment would be associated with the actor Volvo Trucks.

Environmental Performance

The lower use of energy, water and lower waste handling all result in lower impact on the environment. In contrast to traditional zinc-phosphating technology, the chemicals used in silane-based surface treatment do not contain the elements P, Zn and Ni, but they do contain Zr. This has a positive effect on the effluent wastewater.

The use of silane-based surface treatment as a new technology in CS8 will mainly affect EcoWater environmental indicators Climate change, Aquatic Eutrophication, Human Toxicity, Resource Depletion (Minerals and Freshwater). The effect comes from:

- CO_2 emissions generated during production of electricity and district heating (Climate change),

- Pollutants in wastewater, P, Zn and Ni (Aquatic Eutrophication and Human Toxicity),
- Extraction from nature of the elements P, Zn, Ni and Zr (Resource depletion – Minerals),
- Industrial water use (Resource Depletion – Freshwater).

Maturity and Availability

Silane-based surface treatment technology meets the quality criteria for corrosion protection of hot rolled steel. Further development is needed for the technology to also meet the criteria of cold rolled steel. This implies that the technology is not suitable for mixed constructions, made from a combination of hot and cold rolled steel. Of the two Volvo Trucks production sites in Case Study 8, only the Tuve site is appropriate for implementation of silane-based technology. The frame beams treated at Tuve consists of purely hot rolled steel, whereas the truck cabins treated in Umeå consists of mixed steel. (Lindskog, 2014)

Oxsilan® is the trademark for a silane-based surface treatment technology by Chemetall. Oxsilan 9820 has been used for front and rear axles of Opel Insignia, Adam Opel GmbH, Germany, since 2009.

At Volvo Trucks, accelerated corrosion tests and adhesion tests performed for a silane-based coating has been approved. It has been questioned whether those tests, which are configured for traditional phosphating technology, are also valid and comparable to field use of products treated by silane-based technology. Field tests are currently in progress at Volvo Trucks, but they are time-consuming.

5.2.2 Recirculation of water and chemicals

Description

Although it is not a specific technology, but rather making smart use of existing technologies, it is worth mentioning the possibilities of recirculating water and chemicals in the automotive industry.

The rinse water from degreasing and phosphating can be recirculated within the process if it is cleaned to a certain degree fulfilling the quality criteria of the process.

Separation technologies such as membrane filtration and ion exchange are often used for this purpose.

The treatment of the rinse water is more efficient if the drag-out from the process baths is concentrated in a small water volume. This can be done using a multiple counter-current rinse system. A counter-current rinse system should have at least three rinsing steps where clean water is added in the last step.

If possible these rinsing concentrates should be returned into the process baths, if necessary after specific treatment/concentration. By applying this rinsing technology, the process can often be operated as closed water/low waste systems.

Economic Data

Technology costs are case by case specific, depending existing process set-up, chosen solution for water recycling and applied separation technologies.

In the system of CS8, costs for implementation of water recycling solutions would be associated with the actor Volvo Trucks.

Environmental Performance

If this recirculation technology results in a closed water/low waste systems, the impact on the environment will be reduced. Reducing the rinse water volume by 90% can normally be achieved by a three step counter-current rinse. A compete closing of the water system requires evaporation which would increase the energy use.

The current situation at Volvo Trucks is that both production sites in the study have counter-current rinse systems and recycling of water in the process. It might be possible to reach even lower water use by applying additional separation technology for water recycling. However, the described technology will show the biggest benefits for systems that start from a situation of no counter-current rinse and no water recycling.

Maturity and Availability

The separation technologies membrane filtration, ion exchange and evaporation, as well as counter-current rinsing, are well known and often used for this purpose.

5.3 Water Supply Chain Technologies

For the automotive industry, the specific objectives of implementation of innovative technologies in the water supply chain are:

- Resource efficiency (saving energy and reduced use of chemicals),
- Reduced operating costs (as a result of Resource efficiency).

Investment and operation costs of the below described technologies for water treatment, membrane distillation and electro-deionisation, depend on the application. Factors that influence this are e.g. the quality of inlet water and the target water quality to make it suitable for industrial use.

5.3.1 Membrane distillation for water pre-treatment

Description

Membrane distillation (MD) is a chemical unit operation that uses water repellent (hydrophobic) membranes as a barrier for contaminated water. The process takes place at temperatures below 100°C and at ambient pressure.

The transport of vapor is driven by the difference in vapor pressure between the heated side and the cooled side. Heated water flows alongside a micro porous, hydrophobic membrane. The surface tension of the water prevents it from entering the membrane. However, part of the water evaporates and, as vapor, passes through the pores of the membrane to the other side, where it later condenses.

Temperature levels are such that low-grade heat sources may be used to supply the required energy for the process. Unlike other membrane processes, MD does not require a mechanical pressure pump and is not limited by the osmotic pressure.

Trans-membrane fluxes have been measured from 6 L/m^2 per hour in low temperature intervals to 70 L/m^2 per hour in high intervals. Theoretically, trans-membrane flux of approximately 100 L/m^2 per hour is possible. At normal working conditions trans-membrane flux can be assumed to be from 10 to 50 L/m^2 per hour. By applying vacuum to the permeate side, higher fluxes can be achieved.

Membrane distillation could potentially replace the use of reverse osmosis as a water purifying technology before water use in the processes of CS8.

Economic Data

Investment costs depend on the size of implementation. For example, equipment for 3.5 m^3/h had an investment cost of about 220,000 € (costs are not linear, as higher flows mainly need larger membrane area, but costs for i.e. control system basically remain the same).

Several cost items contribute to the operating costs. Full scale equipment might need 1 kWh/m^3 electricity, but also heat (can differ, e.g. 150-200 MJ/m^3). If heat has to be generated or is costly, the technology is probably not competitive, but in cases when waste heat is available the technology can be competitive. Waste heat levels of 80°C may suffice for the MD technology, depending on application.

To safeguard the equipment, a pre-filtration is needed, resulting in a waste stream. Only small amounts of chemicals are needed to clean the system.

Membrane life time is very much dependent on the application, but should be several years. Manpower for operation and maintenance is relatively low due to automatized operation.

In the system of CS8, technology uptake and costs would be associated with the actor Volvo Trucks.

Environmental Performance

Membrane distillation uses heat and electricity to operate. Thus, emissions generated from heat generation and electricity generation have to be taken into account. When using waste heat, this can also be calculated as a positive effect.

The technology creates some waste: a concentrate stream, and waste from pre-treatment. As the source water usually is raw water, the effects from these by-products are usually low. As chemical use is low, the environmental impact from chemical use is also relatively low.

The use of membrane distillation as a new technology in CS8 will mainly affect EcoWater environmental indicator Climate change. The effect comes from CO_2 emissions generated during electricity production.

Maturity and availability

Membrane distillation is available from different suppliers and with different technology solutions. So far, commercial installations are rare and tend to involve demonstration objects, e.g. solar desalination.

5.3.2 *Electro-Deionisation for water pre-treatment.*

Description

Electro-Deionization (EDI) is an alternative process to clean incoming water for industrial processes, where high water quality is needed. It is an alternative process to ion-exchange.

EDI uses an electrical current to regenerate cation and anion resins. It is similar to a combination of electrodialysis and ion-exchange within one process. The ion exchange resins are placed between the ion selective membranes. During the treatment, ions are separated from the water stream by the ion exchange resin. Due to the direct current applied, these ions are also continuously removed from the bed and pass through the semi-permeable membrane into a concentrate stream.

EDI needs a pre-treatment process in order to safeguard the ion-exchange resin. This is usually achieved by reverse osmosis. As EDI is a continuous process, the environmental impacts can be smaller than for conventional ion exchange.

Electro-Deionization in combination with reverse osmosis could potentially replace the use of conventional ion exchange as a water purifying technology before water use in the processes of CS8.

Economic Data

Investment costs depend on the size of implementation. As an example, an RO plus EDI equipment for about 60 m^3/h had a cost of about 680,000 €.

Operating costs are mainly electricity costs, which depend on application and costs at the local installation. An example is 0.7 kWh/m^3 for operation of the process.

Membrane life time is very much dependent on the application, but should be several years. Same goes for ion-exchange resins, which might have a shorter life time, causing replacement of stacks. Manpower for operation and maintenance is relatively low due to automatized operation.

By-products from EDI can often be sent directly to drain, not causing extra costs.

In the system of CS8, technology uptake and costs would be associated with the actor Volvo Trucks.

Environmental Performance

EDI uses mainly electricity for operation, thus environmental impact from electricity production has to be taken into account. By-products are usually not a large environmental issue and no chemicals are used. Further environmental impact arises from the necessary replacement of material, i.e. stacks with membranes and ion-exchange resins.

The use of EDI as a new technology in CS8 will mainly affect EcoWater environmental indicator Climate change. The effect comes from CO_2 emissions generated during electricity production.

Maturity and availability

The technology is commercially available, and is implemented in laboratories, and industries, e.g. power generation. There are a number of larger suppliers providing EDI technology solutions.

6 Concluding remarks

This report includes technological and economic information about innovative technologies with the potential to increase the eco-efficiency of industrial water systems. Table 12 gives an overview of the selection of these technologies.

Table 12. Overview of innovative tehcnologies

No	Name	Stage of Implementation
Textile Industry		
Production Chain Technologies		
T1	Jet Dyeing Machines	Dyeing
T2	Automatic Dye and Chemical Dispensing	Dyeing
T3	Plasma Finishing Technology	Dyeing
T4	Cationization for Salt-Free Dyeing	Dyeing
T5	Use of Natural Dyes	Dyeing
T6	Enzyme Treatment	Desizing
Water Supply Chain Technologies		
T7	Advanced Oxidation Processes	WWTP
T8	High -Technology Filtration Systems	WWTP
Cogeneration Power Plant		
Production Chain Technologies		
T1	Aquifer Thermal Energy Storage (ATES)	Distribution Network
T2	Combined In-house Heat-Power production	Households
T3	Heat distribution network	Distribution Network
Water Supply Chain Technologies		
T4	Smart Cooling by small bubble screens	Water Abstraction
T5	Modified Travelling Water Screens	Water Abstraction
Dairy Industry		
Production Chain Technologies		
T1	Condensation of vapor from spray towers	Dairy Processes
T2	Recovery of CIP baths	Cleaning
Water Supply Chain Technologies		
T3	Anaerobic pre-treatment of wastewater	WWTP
T4	Membrane bio-reactor with polishing/disinfection	WWTP
Automotive Industry		
Production Chain Technologies		
T1	Silane-based metal surface treatment	
T2	Recirculation of water and chemicals	
Water Supply Chain Technologies		
T3	Membrane distillation for water pre-treatment	Water Treatment
T4	Electro-Deionisation for water pre-treatment	Water Treatment

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