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Summary

Access to microbiologically and chemically safe water is limited not only in developing countries, but also in transition countries and even in remote areas of some developed countries. For these cases, point-of-use (POU) technologies can be promising alternatives to centralized treatment concepts. Membrane-based treatment systems have gained importance for drinking water treatment in the developed countries and can be considered as the dominant technology for new applications at present. Due to the high retention of pathogens and the possibility of downscaling (modular construction) membrane technology seems to be attractive also for application as POU system in developing and transition countries. However, no scientific publications on such systems are available and application is limited.

Therefore we conducted an extensive literature and state-of-the art review to evaluate relevance, current use and the research and development needs of membrane-based POU systems in developing and transition countries.

POU technologies are widely being used to produce safe and high quality drinking water in rural areas of industrialized countries, where access to centralized supply is not available, or for additional treatment of tap water. However, the cost level of POU systems applied in industrialized countries is in general not acceptable in other cases. Therefore simple low cost systems were developed and applied in developing and transition countries. In a range of case studies, described in literature, these systems show themselves as an appropriate short term solution, but often fail to provide improved access to necessary amounts of safe water. Economical growth of developing and transition countries leads to increasing public concern, affordability and requires long term sustainable solutions of the drinking water problem. Membrane-based POU/POE systems are especially attractive for application in developing and transition countries while they can provide high removal of bacteria, protozoa and viruses, have modular design and can be operated with a range of different energy sources, including mechanical and hydrodynamic energy.
But, for their application in developing and transition areas, the cost level is in general not acceptable. Furthermore, the source water quality is often very low and can differ regionally as well as seasonally, and the POU/POE systems should be able to treat this kind of waters. Another critical factor in transition and especially in developing countries is the maintenance and control. Not only the level of education of the local population may be insufficient, but also structural financial means for maintenance and control may be lacking.

Contents

1 Introduction

A large proportion of the World's population does not have access to improved or microbiologically safe sources of water for drinking and other essential purposes: at the beginning of 2000 one-sixth (1.1 billion people) of the world’s population was without access to improved water supply. The majority of these people live in Asia and Africa, where rural services still lag far behind urban services (WHO 2000). Despite major efforts to deliver safe, piped, community water to the World's population, the reality is that water supplies delivering safe water will not be available to all people in the near future. The millennium declaration established as a goal halving the proportion of the global population without access to safe water by 2015. In order to achieve this goal it is necessary to understand the reasons and distinguish new strategies of development of water sector.

Point-of-use technologies (POU) are in general known as technologies which are typically applied to treat only the family’s drinking and cooking water at the points such as the kitchen sink, where water is actually drawn for drinking and cooking. If the treatment system is applied where water enters building and provides corrected water to every fixture, faucet and flush in the entire home or complex, such system is known as point-of-entry (POE) system.

The purpose of this report is to overview existing solutions for problems in drinking water supply with the focus on POU and POE technologies and in particular on membrane based POU water treatment systems, as one of the important trends. Today, membrane based POU systems are widely used in developed countries because of their ability to production of high quality water, easy use and maintenance and other advantages discussed in the report. These systems are able to remove numerous contaminations, producing safe and high quality drinking water from contaminated water resources. With the development of these systems, increasing competition on market and, as a consequence, price reduction, POU membrane systems were able to enter the market of developing and transition countries. But due to a number of specific regional problems, membrane based POU systems are still not widely spread in developing countries.

In order to identify situations where POU are useful, this report will provide an overview of drinking water supply problems and possible solutions for rural and urban communities of developing and transition countries. The review considers the analysis of alternative water supply strategies, applied by the population of developing countries in case of insufficient water supply and treatment. Furthermore, current trends in search of possibilities to overcome the water supply difficulties are discussed.

More detailed evaluations are made of membrane based water treatment technologies. The market for such systems in developed countries is analyzed, possible alternative sources of energy for the membrane based treatment process and examples of systems already used in developing and transition countries.

The review is based on existing reports and scientific literature. It was not intended to review all existing solutions for water supply in developing countries or present all possible membrane based technologies. Moreover, such critical factor as distribution and storage of water in the individual households also was not the scope of it.
This review focuses on general trends and most common systems and provides a general background of reasons of membrane POU systems evaluation.

2 Situations where POU systems are relevant

In developed countries, POU/POE water treatment systems have been applied extensively for decades to correct and enhance water quality problems in individual homes (Harrison 1999). In developed countries growth of the market of POU/POE technologies occurred due to the need of purified water in parts of the countryside, which have been newly exploited due to migration of a large number of people to rural areas. In many cases, consumers may not have the financial resources, technical ability or physical space to own and operate custom-built treatment plants. Therefore, small drinking water supply works, especially those serving a population of 500 or less, may also find POU or POE drinking water treatment equipment to be the best solution for providing safe drinking water to individual homes, businesses, apartment buildings, housing developments or even small towns. (Harrison 1999).

In developing and transition countries, the scarcity of safe drinking has necessitated a search for new or alternative water purification techniques (Moyo, Wright et al. 2004). In recent years, point-of-use systems have gained new-found popularity as solutions to water issues in the developing world (Mintz, Bartram et al. 2001). Different POU systems have been applied in different cases, and as discussed below, either helped to solve the problems or failed. Relevance of the POU/POE technologies is much dependent on local socio-cultural, economical and political situation. But nevertheless there are some general situations, typical for developing and transition countries, in which these technologies may be applied. This chapter reviews different problems and situations in developing and transition countries, where POU/POE technologies may be relevant. Some cases, typical for developed world are also described.

2.1 Developing countries

2.1.1 Water quality problems

The main risks associated with water in developing countries are related to biological causes. There are about two dozen infectious diseases whose gravity depends on water quality (Arnal Arnal, Sancho Fernandez et al. 2001). Waterborne infectious diseases are transmitted primarily through contamination of the water sources with excreta of humans and animals, which are either active cases or carriers of the diseases. Use of such water for drinking and cooking, contact with it during bathing and washing, or even inhalation of small droplets as aerosols, may then result in infection (Gadgil 1998). These illnesses can be caused by viruses, bacteria, protozoa or larvae. Other microorganisms present in water are fungi, algae, rotifers and crustaceans (Arnal Arnal, Sancho Fernandez et al. 2001).The minimum infectious dose for the average healthy adult varies widely for various microorganisms. This dose ranges from just a few organisms for *Salmonella typhi* (reason for typhoid), several hundred organisms for *Shigella flexneri* (cause dysentery), several million cells of *Vibrio cholerae* needed to induce cholera. For infants and small children these doses are significantly lower than for the general adult population (Gadgil 1998).

In some cultures, particularly in under-developed countries, water disinfection methods are not usually applied and, in case they are, they cannot guarantee effectiveness. Currently, the most frequently used disinfection method in these countries consists of boiling water, with a consequent waste of energy and limitation of good-quality water amounts imposed by the system. Due to these factors, on many occasions thermal treatment is not applied, and the water is used in the same condition as it was found at the source. This causes a high rate of infections that, although they are not severe in most cases, have been the origin of major epidemics in some instances (Arnal Arnal, Sancho Fernandez et al. 2001). Even if an disinfection agent - mostly chlorine gas or hypochlorites is applied, the presence of suspended matter and colloidal turbidity in the water can protect micro-organisms from effective disinfection and can stimulate bacterial growth (Pryor, Jacobs et al. 1998). Coliform organisms are generally accepted by WHO as indicator organisms for fecal contamination of water and possible presence of pathogens. But although other bacterial pathogens are less or comparably resistant to disinfection as the coliform organisms, enteroviruses and the cysts of some parasites are more resistant. Therefore the absence of coliforms from disinfected water does not necessarily indicate absence of enteroviruses and the cysts of *Cryptosporidium, Giardia*, amoebae and other parasites (Gadgil 1998).

Among the most well-known widespread and significant naturally occurring waterborne toxics are arsenics and fluoride (with guideline maximum concentrations of 10 µg/l and 1.5 mg/l). Field concentrations in drinking water in severe problem areas reach a few mg/l and tens of mg/l respectively, causing arsenic poisoning (and cancer) and crippling skeletal flurosis, respectively. These two chemicals alone affect in the order of a hundred million persons in developing countries (Gadgil 1998). Besides of these two toxics, WHO set guideline TDI (tolerable daily intake) values for the following elements: antimony, barium, boron, cadmium, chromium, copper, lead, manganese, mercury, molybdenum, nickel, selenium and zinc. Guideline TDI values are also set for such compounds and ionic groups like cyanide, nitrate and nitrite. Among organic contaminants, WHO guidelines address the several toxics that increasingly find their way into drinking water supplies in the developing countries, where agricultural chemicals are commonly and uncontrollably used and chemical, dyestuff and process industries are spreading. In this list are chlorinated alkanes, chlorinated ethenes, aromatic hydrocarbons, chlorinated benzenes and 36 pesticides (Gadgil 1998).

Besides of widespread feed water quality problem, the situation in which a substantial proportion of the households does not have access to improved water supply differs for rural communities (2.1.2.) and cities (2.1.3.) and these situations are discussed below in more detail.

2.1.2 *Rural communities of developing countries*

Rural and developing communities are situated further away from the major centers and the management and supervision levels in these areas are significantly reduced (Pryor, Jacobs et al. 1998). In these communities without any supply infrastructure, household members—typically women and children—obtain water for domestic uses from surface water sources, and occasionally from water vendors. The time devoted to water fetching is often substantial, and both quantity and quality of water supply is lacking. Where improved water supply infrastructure is installed - typically shared facilities such as borewells with handpumps - the access is often lacking while the volume of water supplied per capita is insufficient or because the facilities have fallen into disrepair (Lenton 2004).

The reasons for lack of access to adequate supplies of water in such communities are found both in the economics of water supply, as well as in development policy frameworks at the national level. Such settlements are generally unable to exploit economies of scale for community-level water supply solutions, so per-capita costs of improvements are high, while the potential for cash contributions from households tends to be low. Where the water supply infrastructures are installed, their sustainability could be poor as a result of inadequate financial resources for operation and maintenance, unavailability of spare parts or technical skills and/or a weak institutional arrangement for upkeep of the facilities ((Lenton 2004).

Where treatment is practiced, pressure or gravity sand filters with or without coagulation are often used to remove suspended material from the water. Poor maintenance of these systems, loss of filter media over a period of time as well as infrequent washing of the filters can result in sub- standard performance and reduced efficiency of disinfection. Slow sand filtration is also practiced, usually at smaller works and although this performs some natural disinfection, excessive raw water turbidities during high rainfall seasons, operation of the filters at inappropriate flowrates and lack of flow control can result in similar problems (Pryor, Jacobs et al. 1998). Besides of technical and financial problems there is often a persistent lack of health and product information in the rural communities. Failing understanding of the relation between water and disease, or product function can be one cause. Another issue is the incorrect application of household water treatment. In some cases (Murcott 2005) it was found that people were chronically overdosing disinfectant, and afterwards refused to drink water with a strong smell of chlorine, or those who preferred to boil their water had problems with stomach ailments despite using boiled water. Further research revealed that many of these residents often removed the boiling pot of water before or just as it hit a rolling boil, largely to save fuel, thereby drinking contaminated water (Murcott 2005). A further problem is that the traditional approach to provide water/source infrastructure improvements was influenced by the view that "contamination of water in the home is relatively unimportant. What matters is whether the water coming out of the tap or pump is contaminated" (WorldBank, 1992, cited in (Moyo, Wright et al. 2004)). At present there are indications, that water collected for domestic use often becomes microbiologically recontaminated between source and point of use in the home by unsafe consumer storage and handling practice at the household level (WHO 2002). Therefore, the notion that providing clean water sources could be the solution to the rural water supply problem might not be correct (Moyo, Wright et al. 2004).

2.1.3 Urban and peri-urban areas of developing countries

Although the spatial concentration of large numbers of people created by rapid urbanization in the second half of the 20th century has produced a potential for distributional efficiencies not enjoyed by dispersed rural populations, urban water management has often failed to adequately supply large numbers of poorer residents (Basu and Main 2001). In fact, the problems facing the developing world are often related to very rapid urbanization - normally of the very poor. This gives rise to massive shanty towns where the establishment of an infrastructure may be neither economically feasible nor technically desirable (Thomas 2005).

The estimation of population in urban areas with access to reliable water supply, given by WHO, may be set too high. In some cities the water systems abstract unsafe water from unprotected or contaminated sources and deliver it to consumers with no or inadequate treatment, yet these water systems are classified or categorized as improved and safe. Another problem contributing to the underestimation of the population served by unsafe water is contamination of water during distribution whether water is piped or carried into the home. Many cities have protected or improved water supplies and treated water that is microbiologically safe when collected or when it leaves a treatment plant. However, in some urban water supplies the infrastructure for water distribution to consumers is so inadequate that pressure drops, losses and other intermittent pressure changes, deteriorating, open or leaking conveyances, illegal connections and other distribution system deficiencies lead to infiltration or intrusion of contaminated water and increased waterborne disease risks (WHO 2002). Furthermore, in many large cities, including some of the World's megacities, peri-urban settlements are not served by the centralized water system for socio-cultural, economic, political, technological and other reasons. These unserved urban dwellers are forced to make their own informal arrangements. For them, water is obtained mainly from dug wells and handpumps, ponds, tanks and other surface sources. Water vendors and trucks play an important trade, but high charges place their services beyond the means of many poorer people. Both in the corporations and in the municipalities, the water supply deficit is considerably aggravated by leakage in worn pipes and reservoirs, and damaged and neglected roadside stand-posts and public taps (Basu and Main 2001).

Small towns, former villages, that have grown up, but whose infrastructure systems have not yet evolved to a level comparable with large cities are normally excluded both from national water supply programs targeting rural areas, as well as from those focused on cities. They are generally large enough to enjoy some economies of scale of water supply, but too small and/or dispersed for traditional urban utility management models to operate effectively. There often exists in this type of communities the economic capacity to make considerable improvements in water supply, but the absence of a supportive institutional framework often results in a variety of household-level solutions. As the result, some wealthier households are installing private wells, while the others obtain water from vendors and/or surface water sources (Lenton 2004).

2.2 Transition countries. Case of Post Soviet Union Region

In Transition countries very similar problems, often based on the same reasons can be found, but these problems tend to be hidden. While the level of economy of such countries is higher, they are supposed to decide their problems themselves, without support of international organizations. As a result, the information about the situation of drinking water supply is simply not available or not reliable and the quality and availability of water is overestimated. This tendency can be seen in case of Post Soviet Union countries of Eastern Europe and middle Asia.

For the Eastern European region information on drinking water supply coverage in WHO Global water Assessment report (WHO 2000) either is not available (Ukraine, Estonia, Lithuania, Latvia, Georgia, Armenia, Azerbaijan), or represent 99% water supply coverage (Russia, Moldova, Byelorussia). Only for Romania the coverage is reported on the level of 50% supply. The same situation can be seen in the Asian part of former Soviet Union state (Kazakhstan, Uzbekistan, Kyrgyzstan - 99%, Turkmenistan, Tajikistan - not available).

In case of these regions, the existing problems lie not in coverage of supply, but mostly in the quality of it (WHO 2000).

2.2.1 Rural areas of transition countries

In case of transition countries of Post SU region, strong anthropogenic chemical contamination of the drinking water suppliers in rural areas is caused by uncontrolled use of mineral and especially organic fertilizers in the agriculture or widespread industrial pollution in highly industrialized regions. There are evidences, which suggest that concentration of anthropogenic chemical toxics in the drinking water supplies in East Europe and former Soviet Union are higher than those in the rural areas of most developing countries (Gadgil 1998). The most important freshwater pollutants in Eastern Europe and Central Asia are nitrate, pesticides, heavy metals and hydrocarbons, and the most important consequences of this pollution are eutrophication of surface waters and effects on human health. Over-use, resulting in lowering of the water table, is causing salt water to intrude into groundwater in coastal regions (Clarke 2000)

In Ukraine, rural water supply systems are often in very poor conditions comparing to urban systems. Therefore, the rural population used to use groundwater as a decentralized source of water supply. Many of the approximately 127000 sources of non-centralized water systems monitored do not meet established water quality standards, whether Ukrainian standards or EU standards. The most common contaminants of agricultural regions are nitrates, heavy metal ions and high salinity, due to intensive irrigation and rise of ground water level (Tsvetkova 2004). The quality of ground and surface water of industrial rural areas (Donbass) is influenced by inefficiently treated industrial or coal-mine wastewater, landfills and solid waste disposals, wastewater lagoons, oil and petrol storage reservoirs and military sights (Babaev 2000). In some southern rural areas of Ukraine, water is still delivered by trucks, while the salinity of groundwater is too high (Medvedev 2002).

2.2.2 *Urban areas of transition countries*

Widely spread and still strongly centralized water supply systems of most Post SU countries, consisting of drinking water reservoirs, pumping stations, treatment plants and distribution systems – are relatively old. They date back to the 60's and 70's. The notably poor drinking water quality is, to a large extent, caused by the deterioration of the physical infrastructure throughout the 80's and 90's. Many needed investments have not been carried out and most water utilities have not even been able to cover the required operation and maintenance costs due to 10-15 years long economical crisis of the region. The conventional technologies used for drinking water treatment did not change since 60's - 70's, while the water has been deteriorated dramatically due to industrial development of the region, not controlled wastewater discharges or inefficient wastewater treatment (DanishEPA 2003). In case of Ukraine, Russia, and Byelorussia the lack of financial support for governmentally dependent water supply companies results in their unprofitability, because of governmentally determined low water prices.
The risk of contamination of drinking water seriously increases because of inadequate maintenance, which includes breakdowns, leakages (up to 30-40%), discontinuous water supply or mistakes of working personal. Like in case of developing countries, most people boil water before drinking it from public water supply.
In Ukraine, economic growth started in 1998, which increased the affordability of alternative water supply, which resulted in a large increase of the market for bottled water and point-of-use systems. In places with centralized scheduled water supply, the storage tanks, often with additional treatment are widely used by households within a house or a flat-block (Kvashuk 2002; Tsvetkova 2004).

2.3 Special cases

2.3.1 *Regions affected by disasters*

Currently, excluding those caught up in war, about 250 to 300 million people a year are affected by disasters, and this figure is growing at a rate of around 10 million a year. People affected by disasters have more probability of falling ill and dying because of diseases related to unsuitable conditions of sanitation and water supply than any other cause. One of the main problems related to natural disasters concerns the response time of international organizations with regard to delivering of water treatment material. Generally, response time until the first potabilization plant is delivered in around 10 days, too long considering the important role of water in our lives (Arnal Arnal, Sancho Fernandez et al. 2001).

2.3.2 *Specific contamination*

In some places of the world the specific geological conditions, industrial or agricultural misuse caused additional contamination of water with specific compounds. For example, in Finland there is urgent need of radionuclide removal techniques in granite rock areas. In such areas water may contain high levels of Rn and also other natural radionuclides (Huikuri, Salonen et al. 1998). In some regions of India, where ground water is the main source of drinking water excess fluoride content, higher salinity level, excess of iron, arsenic and nitrates in underground water are identified to be the major problems of water quality (Arora, Maheshwari et al. 2004).

2.4 Developed countries

In the developed countries, people with access to improved water supply, being good informed on the quality of water they consume, are often not satisfied with it. As the result, billions of $ are spent by population of developed countries on bottled water and small household treatment systems (Ahmedna, Marshall et al. 2004). The second case in which POU systems may be relevant is additional treatment of water used in care of immunocompromised population. It is proved (Ortolano, McAlister et al. 2005; Sheffer, Stout et al. 2005) that sensitive subpopulations of patients with immunosuppressive conditions such as advanced age, cancer, leukemia, HIVinfection, diabetes, and transplantation are at the greatest risk of infection with health care acquired infections, found in water distribution systems (also in hospitals). These individuals may require a higher standard of care, including purification of the water used in their care.

3 Solutions

3.1 Solutions developed by the population

To cope with interruptions or lack of water supply and with problems in its quality, in many cases the population of the developing regions as well as poor part of population in transition countries has to search for the solutions itself. In every region, or even part of the region or city, possible strategies of self water supply, developed by population, varies due to regional specifics. Generally, people do not rely on government or any external help and start to be managers of their own water supply, discovering different affordable ways to get water themselves. In cities, lack of control and regulation leads to appearance of small private companies, which organize alternative water supply, often with low quality water and much too high prices. There are some case studies which analyze the solutions found and used by population of the large world cities like Amman, Dehli, Calcutta which have problems in drinking water supply. These cases are described below.

In case of Amman (Jordan) (Iskandarani 2003), nearly all of the households are connected to the piped water supply system. However in summer seasons, the public supply is guaranteed only once a week for 12-24 hours, mostly due to water scarcity, infrastructural deficit and population growth. The most common way to deal with the water supply problem for the population is to invest in storage tanks and buy additional water from private vendors at high prices. Because the government has failed to respond to rapidly changing water demands and seasonal water availability, a spontaneous local informal water market has developed. Individually operating water vendors buy water from farmers owning wells and transport water with large tanker trucks over many km to the capital city Amman and other urban areas and then resell the water to individual households at a comparatively high price. Another alternative source is purchases from public water tankers run by water authority. However water supply through public tankers is considered as unreliable due to long response time, and limited volume of trucks. In addition informal water exchange between neighboring households on small scale can be observed. 20% of the households collect rainwater and store it in large cesterns and underground tanks (Iskandarani 2003).

The example of Delhi (India) (Zerah 2000) shows that the problems of water supply lie more in an inefficient management of the supply network than in a scarcity of water resources. Among the important strategies, those concerned with storage are undoubtedly the most widespread. Nearly one-half of population use storage tanks. Around 30% of households reschedule their activities or treat water. Likewise 30% of households pump water from the ground by handpumps or tubewells. This causes uncontrolled depletion of groundwater resources in Dehli, because of the absence of control on private groundwater use and many advantages from the point of view of population, as water is free and not dependent from supply.

In Calcutta (Basu and Main 2001) similar problems and strategies were defined, as in case of Dehli. There water was obtained mainly from dug wells and handpumps, ponds, tanks and other surface sources. In their study Basu and Main tried to determine possible sources of drinking water supply used by population in case of insufficient water supply and their probable contamination. On the basis of the other studies ((Zerah 2000; Iskandarani 2003)) the figure of the alternative urban water supply and distribution, proposed by Basu and Main was extended and generalized. In most cases, when either quality or quantity of water supply is insufficient, ground water is used as alternative, in most cases directly from tube wells or dug wells without any treatment. The storage tanks in case when water is supplied some hours a day or a week, are the most common and easy strategy used by population. Sometimes, when household may financially afford additional small water treatment installations may be used. The other most common sources and ways of self water supply, found by population of cities with insufficient water supply are shown schematically on the figure 1. The figure also represents probable contamination of the drinking water due to feed water quality or inefficient maintenance of infrastructure.

This schema indicates some essential contaminations associated with solutions for lacking water supply. In the described cases, not contaminated water is available in cases of direct use of rainwater, bottled water from a reliable company or in case of domestic POU treatment with appropriate technology. Therefore these technologies are getting now more common, especially in the region where the economical situation is improving and public concern in drinking water quality is growing. The markets of bottled water and point-of-use systems are becoming fast growing industries in such countries as India or China (Jeena, Deepa et al.).

Besides of mentioned technologies, there are a number of possible way-outs developed and proposed by different NGOs, research institutes, and etc., but often the reality is that for each case the appropriate solution differs. Current trends in improving of water quality and access are directed in search of alternatives to conventional centralized water treatment systems. Such concept is based on high costs and investment needs for creating of the centralized water supply infrastructure and keeping it in working conditions, which is not affordable in developing countries, where conventional water supply do not exist. Small scale plants and point-of-entry systems are now studied in cases and have shown to be economically affordable alternatives, especially for rural communities. In poor rural areas of developing countries easy and cheep point-of-use technologies are needed, as the only solution to decrease the amount of people suffering from diarrhea disease, while the contamination of water at the point of use due to lack of sanitation and sanitary education is significant.

In case, when water supply infrastructure exists but falls into disrepair, is in breakdown conditions or provide water with insufficient quality due to numerous leakages and illegal connections, the possible solution is seen in additional water purification at the point-of-use or dual water supply. In semi-arid and arid areas alternative water resources as rainwater harvesting and water recycling are assumed as possible solutions.

But application of appropriate technical and economical solutions is often not the determining factor of acceptability of technology. There are numerous examples where technical solutions failed because of political or socio-cultural reasons. Changes in organizational system, decentralization of the responsibilities, privatization are often factors which can dramatically change the situation in the water supply, unfortunately not always in the side of improvement. Current trends in solving of water supply problem are briefly discussed below in cases.

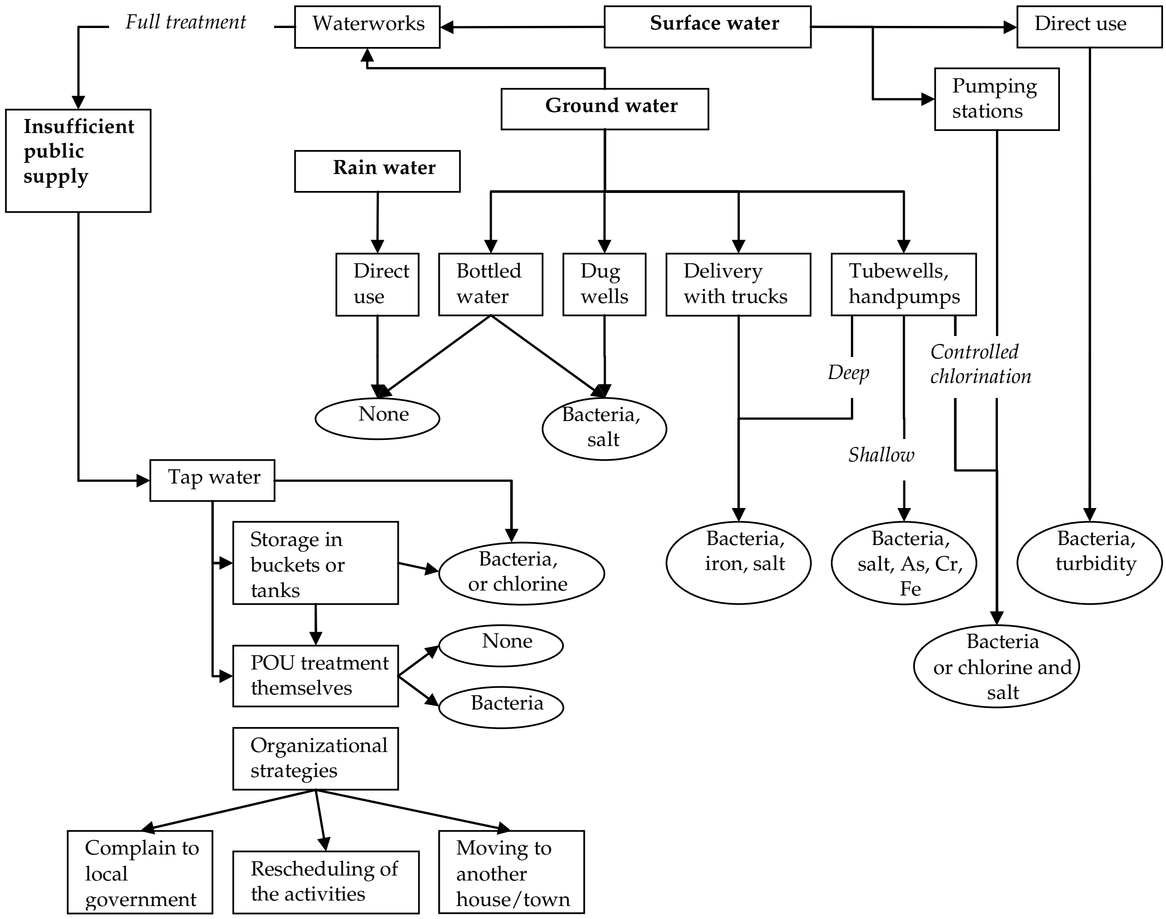

Fig.1 Alternative water sources and strategies, used by population in developing and transition countries in case of insufficient water supply quality or quantity (boxes) and their probable contamination (ovals)

3.2 Current general trends in solving the problems

3.2.1 Decentralization

Case studies from the Andean region, Tunisia and the Dominican Republic were employed to evaluate the impact of decentralization on project sustainability, service delivery and ease and spread of response to consumer demand. Appropriate roles for each level of government, the private sector, communities and other actors were also concerned. Starting from the premise that decentralization itself will not necessarily improve demand responsiveness, there is a need for flexibility and capacity building. Effective decentralization takes time, political will, development of specific skills and clear articulation of the legal institutional roles of each stakeholder. In addition, financial and functional responsibilities must be decentralized together for decentralization to be effective. It was found, however, that in most countries, central governments have been much quicker to decentralize functional responsibilities than to devolve control of funds, often leaving lower levels of government in a difficult position. However positive experience of decentralization also exists. In Columbia there has been a dramatic increase in coverage in the eleven years since decentralization began. This was primarily due to the fact that municipalities receive a significant portion of central funds for water and sanitation service, and have established formal ties with communities to administer provision of such service, enabling them to respond much more effectively to local demand (WorldBank 1999).

3.2.2 *Decentralization of water treatment (dual water treatment)*

The sprawling of cities raises the problem of the infrastructure costs necessary to develop a new urbanized zone, particularly in the case of low-density zones. In the case of drinking water supply, the pipes need to be built outwards from treatment centers. It is also generally considered that for the same quantity of treated water, several small, localized concerns cost more than a single large one. With the aim of adapting to new forms of housing, it may be possible in certain countries, according to the situation, to supply only one flow of water from the treatment plants, of a medium quality that is acceptable for various domestic uses, and then provide an improved individual purification service depending on the final quality desired. This would also match the current rise in demand for security that can be seen at all levels. Water purification at the home would safeguard it against all external pollution, and would be an additional sales point for all types of accommodation equipped with such a system (Prud'homme 2004).

3.2.3 *Dual water supply*

One of the solutions to solve a problem of high quality water supply for drinking and cooking under conditions of low quality raw water supply and deterioration of network was found in Daqing (1 million city in China). The conclusion was made that the costs to improve the whole water supply system were much too high to realize the improvement in reasonable period of time. So, the creation of dual water supply system was proposed as an alternative. It was assumed that only 2.5-5% domestic consumption of tap water is used for drinking and cooking purposes, so so-called polishing water treatment plants (based on ozonation - membrane techniques) using tap water as feed water were created in 7 districts of the city for treating and distributing this 2.5-5% of water. The distribution of treated water was organized separately with independent network, or with bottles (Ma, Sun et al. 1998).

3.2.4 *Alternative water resources: rainwater harvesting*

Rainwater harvesting is a technology used for collecting and storing rainwater from rooftops, the land surfaces, steep slopes, road surfaces or rock catchments using simple techniques such as pots, tanks and cisterns as well as more complex techniques such as underground check dams (Zhu, Zhang et al. 2004). This technology has a potential of addressing spatial and temporal water scarcity for domestic, crop production, livestock development, environmental management and overall water resource management in semi-arid environments (Ngigi 2003). In some semi-arid areas of the world, like for example 50% of the Tanzanian land, the knowledge of rainwater harvesting technology existed and developed for centuries, while people rely completely on rainwater for their survival. These traditional rainwater harvesting systems have been sustainable for centuries and are compatible with local lifestyle and social system (Mbilinyi, Tumbo et al. 2005).

Rainwater harvesting provides water at the point of use and family members have full control of their own systems, which greatly reduces operation and maintenance problems. Supplement of municipal water supplies with harvested rainwater is still suited to both rural and urban areas even in industrial countries. Disadvantages of rainwater harvesting technologies are mainly due to the limited supply, uncertainty of rainfall and often water quality, while harvesting water from for example roads or roofs after dry periods cause its contamination (Zhu, Zhang et al. 2004).

Also, it should be noted, that rainwater harvesting involves abstraction of water in the catchment upstream and may have hydrological impacts on downstream water availability. Therefore, there is concern about the limits of up-scaling rainwater harvesting systems in a river basin (Ngigi, Savenije et al.; Ngigi 2003).

3.2.5 Bottled water

Increased public awareness about waterborne disease outbreaks and lack of safe drinking water supply during travel has resulted in an increased demand for bottled drinking water. For example in India, the use of bottled water may have begun as a fad but industry has evolved into one of the fastest growing industries. There is a common belief that whenever someone purchases packaged water, it is safe. But despite the large market for bottled drinking water in India and proliferation in the number of bottlers, there have been relatively few investigations into public health aspects of these products. The increasing number of bottling plants, even from very limited geographical localities, raises suspicion about the source of high quality water. As the bottled drinking water is consumed without any heat processing, high total heterotrophic bacterial (THB) loads with possible opportunistic pathogens, especially multiple antibiotic resistant forms, can pose definite health risks, especially to immunologically compromised individuals (Jeena, Deepa et al.).

4 Household point-of-use systems

4.1 Purposes and benefits of POU systems

Point of use interventions present an attractive, effective and often inexpensive system of providing portable water to communities in developing and transition countries. The low levels of capital investment of the approach make it particularly attractive for the countries that have reduced resources available (Moyo, Wright et al. 2004).
However, it should be noted that POU systems not always present cheaper solution than centralized systems. In fact it is accepted that in more densely populated areas the economy of scale leads to the opposite conclusion. Centralized water treatment and piped networks may be feasible in at least part of densely populated settlements of developing countries. However, in many cases, efforts to install or improve water supply services in communities of developing countries are frustrated by different financial, political, technological, social and other constraints, considered above (see 2.1-2.3).
Where network services cannot be installed or are in breakdown conditions, promoting alternative water treatment options is often the most feasible way of improving households' water supply situation (Lenton 2004). This give a reason to increase emphasis on home water treatment and storage systems.

The reviews of the household point-of-use water treatment technologies were made by Mintz, WHO and Harrison (Mintz, Reiff et al. 1995; Harrison 1999; Mintz, Bartram et al. 2001; WHO 2002), with respect to developing countries (Mintz and WHO) and developed countries (Harrison). Key differences in the application of these technologies in developing countries compared to developed countries are in the availability and affordability of the materials and the need to adapt the technologies to local conditions and personal or community preferences (Harrison 1999). The variety of systems which were developed, applied and exist on the market is huge, some of them combine different methods or technologies of water treatment and differ in quality, price and amount of people to be served. The most widespread POU technologies used in rural, urban areas of developing countries and developed countries are discussed below in more details.

4.2 POU systems for rural areas of developing countries (choice of WHO)

In rural areas of developing countries point-of-use, point-of-entry and household treatment mostly must be applied to water that is microbiologically contaminated. Therefore, the treatment requirements to achieve acceptable microbiological quality can be substantial and only some technologies or unit process will be capable of meeting this objective (WHO 2002). The efficacy of some treatment methods to physically remove particles (turbidity) and microbes or to inactivate microbes in household water has been documented, primarily for indicator bacteria. Some treatment methods, such as boiling, solar disinfection, UV disinfection with lamps, chlorination and the combined treatments of chemical coagulation-filtration and chlorination have been evaluated for reductions of bacteria, viruses and in some cases protozoans in microbiologically polluted water in developing countries (WHO 2002). Some of these water treatment methods use chemicals and other media and materials that can not be easily obtained locally at reasonable cost and require relatively complex and expensive systems and procedures to treat the water. Such systems may be too inaccessible, complex and expensive to employ for treatment of household water in some places and settings. Besides of this, in rural areas of developing countries water supply infrastructure mostly does not exist, and people deliver water themselves and often use storage tanks or buckets. In these cases, the technologies should be suitable to treat water in storage tanks in point-of-use at home, while contamination of water between source and POU has been considered to be high.

For rural communities of developing countries, (WHO 2002) considers that the following technologies are the most widespread or promising for further development and implementation for application:

- Boiling
- Solar disinfection by the combined action of heat and UV radiation
- Solar disinfection by heat alone ("solar cooking")
- UV disinfection with lamps
- Chlorination plus storage in an appropriate vessel
- Combined systems of chemical coagulation-filtration and chlorine disinfection.

However, wide application of some technologies (e.g. boiling) is caused mostly by customs of the local population and not by its low price or ease in use. Advantages and disadvantages of these technologies are discussed below.

4.2.1 *Boiling or heating with fuel*

Boiling or heating of water with fuel has been used to disinfect household water since ancient times. It is effective in destroying all classes of waterborne pathogens (viruses, bacteria and bacterial spores, fungi and protozoans and helminth ova) and can be effectively applied to all waters, including those high in turbidity or dissolved constituents. A major disadvantage of boiling is its consumption of energy in relation to the availability, cost and sustainability of fuel. In areas of the world where wood, other biomass fuels or fossil fuels are in limited supply and must be purchased, the costs of boiling water are prohibitive. Therefore, boiling household water is unrealistic and inaccessible for many of the world's poorest people due to the scarcity and high cost of fuels and the lack of sustainability of biomass or fossil fuels in the community or region (WHO 2002).

4.2.2 *Solar disinfection by the combined action of heat and UV radiation*

Although boiling with fuel may be a prohibitive option for household treatment of water, heating water, other liquids and other foods to lower temperatures using solar radiation is a more accessible, economical and technologically feasible option than heating with fuel.

The Solar Water Disinfection (SODIS) process is a simple technology used to improve the microbiological quality of drinking water using solar radiation to destroy pathogenic microorganisms. Sunlight is treating the contaminated water through two synergetic mechanisms: radiation in the spectrum of UV-A (wavelength 320-400nm) and increased water temperature. If the water temperatures raises above 50°C, the disinfection process is three times faster (Mintz, Bartram et al. 2001). The SODIS system consist of four basic steps: removing solids from highly turbid (>30 NTU) water by settling or filtration; placing low turbidity water in clear PET bottles of 1-2 liter volume (usually discarded beverage bottles and preferably painted black on one side); aerating the water by vigorous shaking in contact with air and exposing the filled, aerated bottles to full sunlight for about 5 hours (or longer if only part sunlight). The water is exposed to UV radiation in sunlight, primarily UV-A, and becomes heated; both effects contribute to the inactivation of waterborne microbes. The system is suitable for treating small volumes of water (<10L), especially if the water has relatively low turbidity (<30 NTU). Potential limitations of this solar disinfection system are lack of sunlight for disinfection, potential difficulties in treating highly turbid water, lack of a residual disinfectant to protect water during handling and storage and possible objectionable tastes and odors leached into the water from the plastic bottles. While the technology has been hailed for its effectiveness and low cost, some user concerns have arisen. One of the largest concerns was: the process is tedious to perform, and therefore reduces the likelihood that households will adopt the process. In order to supply a family of four or more people, a family would need upwards of 17 two-liter bottles or more for each day. Additionally, the 1- or 2-liter bottles are not the most convenient vessels for household water use. In some cases (Murcott 2005) using drinking water bottles discouraged the users from employing the clean water for anything besides direct drinking from the bottle.
Alternatively to SODIS, if the exterior of the vessel is completely black or similarly capable of absorbing heat (e.g., most metal containers), only thermal effects occur and temperatures can reach >60^{0} C. At these temperatures, water and other liquids can be pasteurized, because most enteric viruses, bacteria and parasites are rapidly inactivated (Ciochetti and Metcalf, 1984).

4.2.3 *UV disinfection with lamps*

The UV radiation technology is simple to use and highly effective for inactivating microbes in drinking water, and it does not introduce chemicals or cause the production of harmful disinfection by-products in the water. UV irradiation with lamps has received renewed interest in recent years because of its well-documented ability to extensively (>99.9%) inactivate two waterborne, chlorine-resistant protozoans, Cryptosporidium parvum oocysts and Giardia lamblia cysts at relatively low doses. But UV lamp disinfection has some disadvantages for use as a drinking water disinfectant at the household level. It does not provide a chemical disinfectant residual to protect the water from recontamination or microbial regrowth after treatment. Particulates, turbidity and certain dissolved constituents can interfere with or reduce microbial inactivation efficiency. A reliable and affordable source of electricity is required to power the UV lamps. The UV lamps require periodic cleaning, especially for systems using submerged lamps, and they have a finite lifespan and must be periodically replaced.

4.2.4 *Chlorination and storage*

Of the drinking water disinfectants, free chlorine is the most widely, easily used and the most affordable. It is highly effective against nearly all waterborne pathogens, with notable exceptions being Cryptosporidium parvum oocysts and Mycobacteria species. For point-of-use water treatment, the most practical forms of free chlorine are liquid sodium hypochlorite, solid calcium hypochlorite, and bleaching powder.

In WHO report the results of 16 case studies, documenting the ability of free chlorine to reduce microbes and to reduce household diarrheal disease when used to disinfect household drinking water in rural areas of developing countries are discussed. The most recent studies done by the US Centers of Disease Control and Prevention include the use of a simple and low cost system of adding chlorine to collected household water stored in a dedicated, narrow-mouth plastic container (preferably with a valved spigot), which has typically reduced waterborne microbes by >99% and reduced community diarrheal disease, including cholera (Mintz et al., 1995; 2001; WHO 2002).

4.2.5 *Combined systems of chemical coagulation-filtration and chlorine disinfection*

Because of the relative complexity of these processes, combined chemical coagulation-filtration and disinfection systems are more difficult to implement at point-of-use for household drinking water supplies even in developed countries. However, purification of water at point-of-use in developing countries using tablets or powders that combine a coagulant-flocculent and a chemical disinfectant have been described (WHO 2002). In South Africa commercial tablets containing chlorine in the form of Halazone p-triazine-trione or dichloro-S-triazine-trione and either aluminum sulfate or proprietary flocculating agents have been developed, evaluated and promoted for community and household water treatment, as well as emergency water treatment. For household use on non-piped, household water supplies it is recommended that the tablets be added to water in a 20-liter bucket. The mixture is stirred to dissolve the tablet and flocculate, then allowed to stand unmixed to settle the flocs and then water is poured through a cloth filter into another bucket. These tablets were found to achieve dramatic reductions of microbial as well as some chemical contaminants in water.

Overall, combined coagulation-flocculation and chlorine disinfection systems have shown considerable promise as microbiological purifiers of household water. Currently, they have not come into widespread use and their worldwide availability is limited at the present time. The relatively high costs of these combined systems may limit their use by some of the world’s poorest people, but market studies (according to WHO) also are under way to determine consumers' willingness to pay. Therefore, these combined systems may prove to be appropriate technologies for household water treatment in many settings for the large segment of the world's population now collecting and storing water for household use (WHO 2002).

4.3 POU systems for urban and peri-urban areas

According to (Lenton 2004), urban areas lacking water supply infrastructure typically fall into two categories: (a) newly constructed neighborhoods to which trunk lines have not yet been extended; and (b) unregularized areas where the installation of trunk infrastructure is costly and/or prohibited by law. Households in this kind of communities typically obtain water from vendors (ranging from pole vendors to tankers); from privately or communally managed stationary tanks; or from friends, family, or employers located in networked areas. In this case, the storage of water in tanks at home the same way as in rural areas is also the most preferred by population strategy. In this kind of urban areas, the technologies, which could be applied for water treatment at home in storage tanks are the same as in case of rural areas.

Like it was discussed above (3.1) water delivered by vendors is in a lot of cases non-treated ground water, which often has low turbidity but may be highly chemically contaminated (arsenic, salt, fluorine and etc.). In such cases, this water to be safe, besides of disinfection may require additional treatment. There are a number of technologies which can remove arsenic, fluorine and etc. from drinking water. Activated alumina is a special application of the adsorption process frequently used to remove fluoride (Craun 1999). Generally activated alumina also can be used to remove arsenic, selenium, silica and humic substances from water. A technology based on filtration of water through ceramic candle filters, in which candles were replaced with activated alumina bags was proposed by Deb and Gupta (Deb 1999) for removal of arsenic from groundwater in West Bengal. (Karthikeyan 1994) also proposed an activated alumina filtration technology for defluoridation of water in Sri Lanka. The other fluoride removal techniques for households in Sri Lanka was proposed by (Padmasiri 1994). They developed a filter, which could be produced locally at cost of US$20 on the basis of locally available low temperature burnt clay. The top of the filter was covered with 5 cm thick layer of coconut shell charcoal.

(Wegelin 2000), EAWAG proposed photooxidation technology for arsenic removal in the presence of lemon juice - SORAS. The process uses the same plastic bottle technique as in case of SODIS and can be applied to iron contaminated water. Citrates, by forming Fe (III) citrate complexes that are photolyzed with high quantum yields, strongly accelerated As (III) oxidation. The photoproduct of citrate includes rapid flocculation and precipitation of Fe (III) (Wegelin 2000).

In urban areas with existing but deteriorated infrastructure the water is often available in the amounts required, but the quality of it is low. In this case, the performance of POU technologies may be similar (but cheaper) to that in developed countries, while people can afford more expensive but more convenient technologies, which can be installed at home under a sink. Adsorption and filtration are often used for additional water treatment at home. These two technologies are briefly discussed below.

4.3.1 *Filtration. Porous ceramic filters*

Ceramic filters act mainly by physically removing particles from the solution. The ceramic filters produced in the developed countries of the world are rated to have micron or sub-micron pore sizes that efficiently remove bacteria as well as parasites. Many ceramic filters are composed with media capable of adsorbing viruses and in principle can achieve high virus removal efficiencies (WHO 2002). Modern ceramic filters for household use are produced in the form of vessels or hollow cylindrical "candles". Water generally passes from the exterior of the candle to the inside. All porous ceramic filters require regular cleaning to remove accumulated material and restore normal flow rate. Porous ceramic filters are made of various mineral media, including various types of clays, diatomaceous earth or glass. They are easy to use and potentially sustainable technology. Low cost ceramic filters are being produced in different parts of the developing world with the assistance of the organization "Potters for Peace". The availability of the suitable raw materials and the appropriate technology to blend these raw materials, shape the filter units and then fire them in a kiln are the main technical and accessibility barriers to their availability in developing countries. Besides of this, the main barriers to the production, distribution and use of fired or unfired ceramic filters-adsorbers are the availability of the trained workers, fabrication and distribution facilities and costs (WHO 2002; Murcott 2005).

4.3.2 *Adsorption*

Adsorption processes and adsorbents such as charcoal, clay, glass and various types of organic matter have been used for water treatment since ancient times. Some of these adsorption processes tend to overlap with either filtration processes, because the media are often used in the form of a filter through which water is passed, or coagulation processes, because they may be combined with chemical coagulants. Therefore, adsorption processes can be carried out concurrently with filtration or coagulation. Charcoal and activated carbon have been used extensively as adsorbents for water treatment in the developed and developing world. The main application of activated carbon is the reduction of toxic organic compounds as well as objectionable taste and odor compounds in the water and in special cases - radon removal (WHO 2002). But it is not very effective in removing of inorganic chemicals that easy dissolve in water, e.g. nitrates and most metals (Craun 1999). For point-of-use or household water treatment granular or pressed carbon block is typically used.

4.4 POU systems, widely applied in developed countries

In developed countries the exodus of millions of people into rural areas has created the need for purified water in new parts of the countryside. In municipalities, bottled water sales continue to grow at double-digit rates due to concerns over the quality and taste of the municipal water supply and the market of POU systems is increasing with the same rate. The evolution of this sector in developed countries is an important driver for investigation and development of POU membrane systems. This, together with increasing competition on the market leads to price reduction, improvement and

prolongation of an exploitation period of the devices, which makes them more affordable for the households of developing and transition countries.
In developed countries treatment efficiency and quality of purified water often are the most important factors of evaluation of the technology, while affordability is much higher than in developing countries. Not only microbiological quality but also chemical contamination is in higher concern. Furthermore, point-of-use or point-of-entry treatment devices or systems in developed countries are often being applied to waters already subjected to extensive treatment, including disinfection, or withdrawn from high quality water sources. Hence, such waters are already likely to be relatively safe or low risk with respect to microbial quality and waterborne disease risks without point-of-use or point-of-entry treatment (Craun 1999).
In developed countries manufactures of household systems normally apply the same basic technologies used by industry and community water systems to purify water but design them for smaller water volumes and flows. To achieve better treatment efficiency, producers often pack several treatment processes into a single module. For example water can pass through a filtering unit to remove particles, algae and reduce microbial contaminants, through a second unit to remove several chemicals and through a third unit for disinfection of any remaining microbial contaminants. An activated carbon unit can be included to remove certain organic compounds, or an activated carbon block can be used to provide adsorption of organic chemicals and reduction of protozoa. When followed by ultraviolet light disinfection, the activated carbon block unit can also effectively inactivate viruses and bacteria (Craun 1999). Besides of activated carbon filtration briefly considered above (4.3.2.) membrane based technologies are the most widespread technologies used in POU in developed countries. These technologies are discussed in detail below (4.6.).
In regions with water scarcity but high financial possibilities and cheep energy sources, sea water desalination technologies are common. The capacity of these systems may range from small (POU/POE) to large (serving cities). Sea water desalination systems mostly are based on distillation, elecrtodialysis and reverse osmosis. Sea water desalination technologies, being very specific for some developed countries, are not the topic of this report and do not discussed here.

4.5 Comparison of household treatment methods used in both developing and developed countries

In table 1, the treatment efficiency and price of only some general but most widely used methods for POU/POE are compared (based on (WHO 2002) and (Craun 1999), as well as market information). This comparison is generalized and can be differ for some treatment systems in specific cases.

Table 1. Comparison of the POU/POE treatment methods according to the (WHO 2002), (Craun 1999) and information from the market:

Criterion	**Boiling with fuel**	**Solar disinfection with UV+heat**	**Solar disinfection with heat only**	**UV disinfection with lamps**	**Free chlorine and storage in improved vessel**	**Combined coagulation - filtration and chlorination**	**Activated carbon filters**	**Reverse osmosis units**
Contaminants removed	Microbial	Microbial	Microbial	Microbial	Microbial	Microbial, Turbidity, Inorganic Chemicals and some metals	Microbial, organic chemical, Radon, odors	Microbial, inorganic and organic chemicals, Radium, metals, salinity
Disinfectant residual, chemical changes	No, expect deoxygenating and precipitation	No, not significant	No, not significant	No, not significant	Yes, may cause taste and odor and disinfection by-products	Yes, may cause taste and odor and disinfection by-products	no	no
Quality requirements of water to be treated	No	Low turbidity (<30NTU)	None	Low turbidity (<30NTU) and low in UV adsorbing solutes (NOM, Fe, sulfites)	Low turbidity (<30NTU) and low chlorune demand for effective use	No, applicable for poor feed water quality	low turbidity	Needs pretreatment for poor water quality, low turbidity
Microbial regrowth potential in treated water	after storage beyond 1-2days	after storage beyond 1-2days	after storage beyond 1-2days	after storage beyond 1-2days	No to low if chlorine residual maintained	No to low if chlorine residual maintained	after storage beyond 1-2days,	after storage beyond 1-2days
Skill levels of users	Low skills, easy use	Low skills, very easy use	Low skills, easy use with training	Moderate skills, training	Low skills, easy use with training	Moderate, training	Easy use with training, moderate - for replacement	Easy use with training, moderate - for replacement
Imported items	No	No if bottles available	Solar cooker or other solar reflector	UV lamps and housing	Hypochlorite generator and hardware for production and bulk storage	Chemical coagulant and chlorine mixture as powder	Filter, activated carbon	RO system
Initial costs	cook pot	bottles available, black paint or dark surface	Initial cost of solar cooker and exposure and storage vessels	Initial costs of UV system (100-300$)	Initial costs of vessel (2-8$)	Treatment and storage vessels (5-10$ each)	Costs of filter and activated carbon (20-100$)	RO Unit (100-300$)
Operating costs	varies with fuel price, expensive	none	Replacement costs of the system	Energy and lamp replacement (10-100$/ year)	1-3$, depends on the source of chlorine and vessel	Chemicals costs at about 35-55$ per household per year	Replacement costs of activated carbon	Energy, replacement costs of prefilter(30-60$/ year), membrane (60-80$ per 3-4 years)

Generally, over 2000 incorporated companies are members of the Water Quality Association and are in the business of designing, manufacturing, selling, installing and maintaining home water treatment products. The

selection of appropriate system is based normally on the water resource conditions, treatment efficiency, affordability and availability on the market, socio-cultural and traditional preferences, political and economical situation, education, concern about water quality and influence of NGOs or advertisements. Necessity to take into account all these factors is essential and introduction or application of the system by experts from outside may lead to fail, if one or some of these factors is forgotten or has been left without attention (Craun 1999). Cases when people refused to drink water after chlorination because of smell, to filter water with fluorine through activated carbon made from animal bones, because of religion background, or to use muddy pond water for SODIS treatment instead of clear but contaminated groundwater and etc. are well known and have been described.
The analysis of the alternative water supply strategies showed that in case of insufficient water supply, population of urban areas of developing and transition countries normally use non-treated groundwater either from tube or dug wells, or delivered by vendors or sometimes bottled. Besides of microbiological contamination, this water may in general be contaminated with chemicals, such as arsenic, fluoride, iron, salinity, pesticides etc. The situation in rural areas is in most cases worse, as water is normally used like it was found at the source. Therefore, this water needs special treatment which in local conditions can be probably achieved with POU or POE technologies. The other possible solutions, discussed in report (dual water supply, rainwater harvesting, bottled water etc.), may be suitable for some specific cases, but in general cannot be considered as a unified solution for the poor areas of developing countries.

4.6 Membrane based POU/POE systems

Whereas in the past membrane processes were typically used for desalting purposes alone, they are now being employed for multiple purposes, including desalting, disinfection by-products control, disinfection, clarification, and removal of inorganic and synthetic organic chemicals (Jacangelo, Rhodes Trussell et al. 1997).
In developed countries their more widespread use can be attributed to several factors:
an increase in number and stringency of water quality regulations, that cannot be effectively removed by conventional treatment processes;
a decrease in high quality freshwater supplies and increased emphasis on the use of brackish water or reclaimed wastewater as a source;
better membrane performance and lower costs due to technological advances;
and development of new applications for membrane processes (Craun 1999).
Membrane based systems are getting widely used as an effective water disinfection method. The protozoa *Giardia* and *Cryptosporidium* have been the principal organisms controlling disinfection regulations over the last decade. While traditional media filtration processes can remove between 1.5 and 4.5 logs of the cysts of these protozoa, their removal is not absolute. Moreover, *Cryptosporidium* is especially resistant to traditional disinfectants like chlorine and chloramines. Therefore, membrane techniques won now popularity in

purifying water in general and also in specific cases, e.g. for care of immunocompromised population (Craun 1999; Sheffer, Stout et al. 2005).

4.6.1 *RO and NF*

The traditional driving force responsible for the growth of membrane technology, and specially RO has been desalting. Today RO and ED account for approximately 23% and 5% of the worldwide desalting capacity, which include most of newly built desalting plants. Reduction in the costs and the energy intensity of reverse osmosis as well as improvements in its reliability leads to slowly replacement of distillation with RO or ED desalting (Schiffler 2004). RO systems are able to reject up to 99% of various dissolved aesthetic-related contaminants and particles, and such health related contaminants as pentavalent arsenic, asbestos, pesticides, herbicides, fluoride, lead, mercury, nitrate and radium. RO systems mostly are effective for biological pathogens like *Cryptosporidium* (Harrison 1999). For groundwaters, RO and NF are employed only with pretreatment (cartridge filtration, pH adjustment, addition of sequestering agent) for removal of salt or NOM. However for surface water or water reuse applications, in most cases more extensive pretreatment for RO and NF is required. In such cases, integrated membrane systems using dual membrane treatment are being investigated on a more widespread basis. UF or MF is employed as pretreatment for high pressure membrane applications (Jacangelo, Rhodes Trussell et al. 1997). Other solutions were applied in cases of application of RO in household water treatment systems. Some stages of sediment microfiltration or activated carbon filtration are used for pretreatment.

4.6.2 *UF and MF*

MF and UF with only prescreening as pretreatment is employed for particle and microbial removal. These processes are operated with only residual disinfection in many surface water applications. However, this membrane treatment scenario does not remove substantial levels of natural organic matter. Consequently, these processes can be employed in conjunction with a coagulant or adsorbent to provide greater removal of organic compounds or DBP precursors of concern to the drinking water community (Jacangelo, Rhodes Trussell et al. 1997).

Beginning of 1990, the first microfiltration/ultrafiltration plants were installed to treat municipal surface water supplies. The driver was implementation of an EPA surface water treatment rule requiring all utilities in the USA to provide and log removal value (LRV) of 3 for *Giardia* and an LRV of 4 for viruses. European regulations have adopted similar rules. The most of plants installed have been equipped with hollow fiber membrane modules. A typical operation scheme for the modules included operation in a dead-end mode for 10-20 min and than backflushing with air or filtered water for 20-30s. In the starting period, many of these water works were small, but nowadays also many large plants equipped with hundreds or thousands of modules are installed or under construction (Baker 2004).

Because of the large variation of pore sizes (0.05-5 µm) and membrane materials associated with MF or UF, the removal of NOM is always considerably less than by NF and is membrane and water specific.
One of the primary applications of MF and UF is for the removal of microorganisms. Viruses are the smallest organisms of concern to the water community, ranging from 0.02 to 0.08µm, followed by bacteria (0.5-10 µm) and protozoan cysts and oocysts (3-15 µm). The pore sizes for MF and UF range from 0.01 to 5µm. Through examination of the sizes of the target organisms and the range of membrane pore sizes, it is apparent that removal of these organisms is specific to the particular membrane and its pore size distribution, when considering the membrane as a simple physical barrier (Jacangelo, Rhodes Trussell et al. 1997).
In summary, it is generally accepted today in the scientific community that MF and UF can provide complete removal of most bacteria and all protozoan cysts of concern as long as the membrane and associated system components are intact and operating correctly. In the case of UF, virus removal is also achieved.
According to (Craun 1999) at present time, low pressure RO units are available for residential drinking water and ultrafiltration and nanofiltration processes are not used for personal or residential water treatment units. But analysis of the technologies represented on the market of POU/POE water treatment systems shows also development and application of POE systems on the basis of ultrafiltration technology.

4.6.3 Market overview: developed countries

The same industrial grade membranes that have been applied in large-scale water treatment plants around the globe have been incorporated into POU/POE water purifiers, developed for residential point of use/entry and small commercial/industrial applications.
The global directory for environmental technology (GreenPages) represents on its "green pages" 531 companies (governmental and nongovernmental organizations, utility companies, importers, engineering consulting and etc.) working on the market or in a field of membrane technology. At least a quarter of these companies, produce, import or provide services of POU/POE membrane based systems.
Most of the POU systems represented, use reverse osmosis membrane as a key element of water treatment. RO is a membrane filter process capable of removing all pathogens and most organic and inorganic contaminants. Some chemical contaminants are removed better than the others - their removal is affected by the type of membrane used (Craun 1999). But in general, POU water treatment technology is represented as a multiple stage process, which, besides of an RO membrane include pretreatment and post treatment stages (AMI; AMPAC; APEC; FountainSofteners; Novatec; WESE; WGSI).
Typical pretreatment stages include sediment filters and activated carbon (sometimes multiple stages). Post treatment stages, when applied in the system, also include activated carbon filter. The function of activated carbon on a pretreatment stage is mostly removal of colloids, chlorine, color, tastes and odor; activated carbon as post treatment stage is probably intended to remove taste, odors and remaining contaminants.

The technology can vary, depending from the producer, but in most cases the differences are not very big. In case of APEC, a second pretreatment activated carbon filtration is included. In *Ami Membranes*^{R} (USA) systems the second stage is replaced with GAC Cartridge. *Fountain softeners* (UK) use a 1 µm sediment filter on the second stage and an activated carbon pre-filter on third. Often spiral-wound membrane modules are used. Such systems are normally installed to purify tap water from centralized drinking water supply or well water, and can be placed under a sink in a kitchen. They work without electric supply, while necessary pressure is provided with the feed tap water pressure in the system. (Sometimes electric supply is used when the system includes a monitoring or water quality control system). Feed water pressure needed for operation varies in range from 35 to 100 psi. Automatic shut off is normally provided in such a system, as well as a storage tank (mostly polypropylene, volume depends from efficiency of the system). The maintenance of the system in most cases requires changes of three pre-filters once a year, which in developed countries can easily be done by customer. In some cases the term of use of pre-filters is shortened till 6 month (*Fountain softeners*). Post filters require changes in 12-18 month, while the recommended time of safe use of RO membranes is 2-3 years. RO systems are normally rated (and priced) with their flow rates. The price of the system varies in range from 200 to 700$ (*APEC, NOVATEC, AMI membranes, etc.*). Prices of each component needed to be replaced varies form 40-50 $ for the pretreatment filters set, till 60-90$ for the RO replacement, resulting in annual operation costs of 85-135$.
Most systems have also limitations in some feed water quality parameters. For example, for *Novatek* (Canada) mentions for its RO home installations: turbidity (<1.0NTU), residual chlorine (Cl_2 < 2.0 mg/l), hardness (<350 mg/l), iron, manganese, calcium and hydrogen sulfide, temperature (T=4-38^{0}C), TDS (<2000 mg/l). In case of *Ami Membranes* Chlorine tolerance is equal to 0, the temperature limit is 45^{0}C, and pH range 2-11. Such systems as *APEC* are able to provide 135-340 liters of drinking water per day. When the pressure of water source is less than 35 psi (case of rural water supply with low pressure, well water or higher concentrations of total dissolved solids) a booster pump is recommended to install. In general this kind of multiple stage RO systems are complex and relatively expensive installations, which require service and replacement of parts and defined source water quality. Therefore, even if they are widely used and accepted in developed countries, their application in developing countries is not realistic.

4.6.4 *Ultrafiltration POU or small scale units in developed and developing countries*

POU systems on the basis of ultrafiltration technology are not very common in household drinking water treatment. Some POE technologies are available on the market, and they also have a pretreatment stage and hollow fiber membrane modules. One of the most applied Ultrafiltration POE home water treatment systems, suitable for a wide range of feed water qualities is *Homespring* (Homespring), developed by *Zenon*^{R} (Zenon). This kind of system supposes to provide good quality water to the whole house (POE), and not only to the faucet in the kitchen like the systems described before. Also this installation includes activated carbon filter as a pretreatment stage. The

ultrafiltration hollow fiber membrane is a key part of the system, supposing to remove bacteria, cysts and viruses. The system is designed to treat surface, well or tap water without other pretreatment. As well as RO systems, *Homespring* does not use electricity to filter water, and annual maintenance is required, while carbon filter capacity is the limiting parameter of the process capacity, and it needs to be changed once a year. These systems are designed to provide a continuous flow 14-17 l/min, or approx. 850-1050 l/day.
Arnal Arnal (Arnal Arnal, Sancho Fernandez et al. 2001) proposed an ultrafiltration system also suitable for application to urban supply in underdeveloped countries. The proposed membrane module has a treatment capacity of 1000 l/d and the number of membrane modules can be extended unlimitedly, with a consequent increase in the treated product flow, adapting to the case and demand. The ultrafiltration module is equipped with a polysulfone spiral-wound membrane with a cut-off of 100 kDa. Before entering the feed tank of the UF facility, the feed water is firstly pretreated in a series of different filtration units:

- coarse filter
- microfilter (500 µm)
- security filter (5 µm)

This UF system is allowing the production of approximately 1000 l/d of treated water per membrane module, and while working on a top efficiency, this can provide water for direct consumption for 300 people per day.
A modification of the equipment was carried out to supply water directly from a source to small communities, which are geographically isolated and where water or electrical supply is missing. The module was provided with manually operated wheel, rotation of which produces energy for the pump. This manual ultrafiltration plant can provide water for direct consumption of max. 300 people per day, working on top efficiency (Arnal Arnal, Sancho Fernandez et al. 2001; Arnal, Fernandez et al. 2002; Arnal, Sancho et al. 2004). The projected manual plant does not require any fuel or additional power source, facilitating its application, and has a compact design to allow for easy handling and transport (Arnal Arnal, Sancho Fernandez et al. 2001).
Opalium (France) proposes some small-scale MF and UF plants, which can be applied for drinking water treatment or as emergency drinking water units. The UF membrane modules OPAMEM, developed by Opalium (France) are hollow fiber modules with a 0.01 µm cut-off, made from chlorine resistant polyethersulphone. The unit operates in dead-end or cross-flow inside-outside mode, with backwashing for cleaning and has a capacity range up to 240 m^3/h per unit.
There are also examples of application of UF as a pretreatment stage for NF or RO treatment. The ROSI system, developed by (Schaefer 2005) is able to deliver potable water from a variety of sources, ranging from high turbidity surface waters to high salinity brackish water. The filtration process consists of two stages - the pretreatment stage uses an ultrafiltration membrane, which is followed by the desalination stage - an RO or NF membrane. The UF membrane removes most pathogens like bacteria as well as particles and some colloidal material, which protects the RO/NF membrane from excessive fouling, in particular - bio-fouling, and hence reduces the cleaning frequency of the modules. The RO/NF membrane retains ionic species and organic

material, decreasing salinity and a proportion of harmful trace contaminants, as well as dissolved organic matter (Schaefer 2005). The described system is also specific, while the basic design concept for it is to use photovoltaic or solar modules. These provide electric power to the pumps that produce the driving force for the membrane process. Some other systems, based on alternative energy supply are described later (4.6.6.).

4.6.5 *Specific contaminations*

Radionuclide removal techniques are urgently needed in Finland in the suburbs of some cities and mainly in dispersed rural settlements where people derive their drinking water from private drilled wells and where there is no communal water supply. High concentrations of radionuclides occur mainly in granite rocks areas. In such areas water may contain high levels of Rn and also other natural radionuclides. U occurs quite often simultaneously with Rn, but Ra226, Pb210 and Po210 less frequently. RO is one of the few water treatment methods which can be applied for the simultaneous removal of U, Ra, Pb, Po and water salinity. A small commercial POE (point of entry) reverse osmosis (RO) equipment was tested for removing simultaneously water radioactivity and salinity from bedrock water in a private household. The system included the same pretreatment stages as the other point-of-use RO systems described above: sediment pre-filter, activated carbon filter and RO module - spiral wound thin film composite membrane (aromatic polyamide) with productivity 225 liters/day (Huikuri, Salonen et al. 1998).
Groundwater forms a major source of drinking water supply for urban and rural areas of India. The major problems identified are excess fluoride content, higher salinity level and excess of iron, arsenic and nitrates in underground water. The study of Arora (Arora, Maheshwari et al. 2004) is concerned specifically with the RO separation of fluoride present in water with the optimization of different parameters to get maximum fluoride removal efficiency. Experiments were done with a membrane of spiral-wound configuration, as productivity of such type of membranes was significantly high at low pressures. The RO process under study had proven to be a very efficient process for defluoridation of drinking water supplies, because it worked at very low pressures and, in addition to fluoride, other inorganic pollutants were also removed without making any additional effort.

4.6.6 *Alternative energy sources*

In many areas of the world where there are water quality or supply problems, there are usually energy supply problems, too. Any standard treatment technology that requires electricity can be operated from a hydro, photovoltaic power (PV), solar thermal, or wind - electric system. But the energy efficiency of the standard treatment technology is a factor in the overall system costs.
With solar and wind direct water pumping systems, the energy is stored as pumped water instead of electrochemically. The capacity of the pumping system is designed in such a way that the average daily water demand is pumped during daylight hours or times of adequate wind speeds. With high temperature solar-thermal systems, the thermal energy can be stored using

the working fluid or a secondary fluid coupled with the working fluid through a heat exchanger. PV generates DC electricity directly from the sun with no moving parts. The PV generated electricity can be used directly or stored in the batteries. The most commonly available PV modules are flat plate crystalline silicon, although other types should give similar performance and reliability. Most modules are warranted for specific power output for 10 years or more.

Wind turbines are very effective electrical generators if there is an adequate wind resource. The modern wind turbines that produce electricity consistently outperform older style windmills, which produce mechanic motion. The efficiency of wind turbines is almost twice higher than windmills, but nonetheless mechanical windmills are still in use and are being sold throughout the world. They are simple devices that are easy to repair when mechanical engineering skills are locally available (Stafford 1999).

Alternative energy sources described above are being used in desalination technology (see 4.6.8). But also other drinking water treatment systems based on membrane technology with solar or wind generated energy supply have already been developed and proposed for both developing and developed world (see 4.6.7).

4.6.7 Medium to large- scale membrane systems with solar energy supply

Solco's Solarflow system (Solco) has been designed to meet the needs of clean drinking water in remote communities, located away from conventional power. The *Solarflow* System combines *Solarflow* reverse osmosis unit with a *Sun Mill* solar water pump, a Sun Tracer tracking array, solar panels and storage tanks (Solco). The System can be erected wherever clean water is required as long as an acceptable water source is in the proximity.

The *Solarflow* is a reverse osmosis unit, specifically designed for operation from solar panels. Because of the energy efficient design, (up to four times more efficient than a conventional reverse osmosis unit) the unit may be powered directly from a single solar module. The *Solarflow* system is completely automatic and has been designed for easy periodic maintenance. Their application can be most needed in isolated/indigenous communities and remote medical outposts, when water is contaminated (Solco).

A *Sun Mill* (Solco) solar water pump delivers pre-treated water to a header tank on the Solarflow system from a water source (bore, well, dam, soak, river etc). Up to 4500L is stored in the tank, which may be used for any non-potable purpose such as washing. Water from the header tank is filtered once again, driven by the static head pressure combined with the positive displacement piston pump in the reverse osmosis Solarflow unit. The pump then forces the pre-filtered feed water through a spiral membrane, housed in a cylinder. Approximately 15% of the pumped water is purified leaving the remaining water to constantly flush the membrane, which minimizes contaminant build-up and hence maintenance requirements. The wastewater, which is still pressurized, is then used to pump more water through the system via energy recovery system. This system makes the unit self-starting and self-regulating at all operational speeds from sunrise to sunset and also enables battery-free operation.

The *Skyhydrant™* (Solco) unit is a simple potable water filtration system intended for sustainable low cost purification. It can be used for developing communities without access to medium term water supply and purification as well selected disaster relief applications. The *Skyhydrant™*, developed by *Memcor* in cooperation with *Skyjuice Foundation* can produce a guaranteed minimum of 10000 liters of drinking water per day. The technology is based on a self-contained membrane filtration system that operates under minimal head conditions without the need for power and/or conditioning chemicals. It is intended to be used on poor quality feed waters such as surface water or ground water where conventional purification technologies may be unable to produce acceptable treated potable water. The design is compact, robust and self-cleaning. It is intended for efficient transport and deployment with minimal training and operator interface. But the *Skyhydrant™* unit is not intended to treat feed waters that are brackish, saline or salt-affected (Solco). The other reverse osmosis unit (*ROSI*), which use photovaltic or solar modules to provide electric supply to the pumps was briefly considered above (see 4.6.4.).

The problem of electricity requirement is often shown as a main problem of the membrane based systems, but in case when groundwater is used, energy is anyway needed to pump water up. So, the same energy sources, as in case of water pumping, also can be used for water treatment: besides of public electric net, manual energy (hand pumps in case of water pumping), diesel electric generators (mostly too expensive energy source), wind mills and wind turbines and various types of solar energy utilization. As it was discussed above, the devices, working on alternative energy sources are being developed but the appropriate solution for energy supply differs vary because of the regional conditions. Also, it is important to consider that installation of alternative energy supply requires investments.

4.6.8 Small scale membrane systems with alternative energy supply

The information of application of alternative energy sources to water supply systems is scarce. But the experience of their use on small scale RO and electrodialysis desalination plants in areas with water stress is already significant.

Small-scale desalination plants might be the most economical solution for providing potable water to remote and isolated communities where the proper infrastructure is lacking but the potential of renewable energy is enormous (Bouchekima 2003).

In the state of Bachrain solar energy seems to be the best renewable source of energy to provide at least a part of the electricity demand. Haitham Al-Quahtani proposed a system, consisting of solar panels, a sediment filter, a pump and a spiral wound RO membrane to desalinate sea water directly in the houses in point of use. The results proved that installation of such point-of-use systems on houses in Bahrain could save 55 million m^3 of natural gas annually (Al-Qahtani 1996).

The central unit of the solar desalination plant, installed on the Emirate of Abu Dhabi, described by Lindemann, consists of a spiral wound seawater membrane for a maximum potable water production of 3 m^3 per day. Due to the sea water supply by a nearby beach well, two cartridge filters are sufficient for the pre-treatment of the feed water. The energy supply of the RO plant is realized by a stand alone photovoltaic generator. This is a suitable solution for relatively small quantities of good quality drinking water. The yearly average of the daily solar irradiation on a horizontal surface at the site was 5.6 kWh/m^2. The proposed system allowed the extension by means of additional energy source (PV module, wind generator or diesel generator) (Lindemann 2004).

Generally, desalination plants are located on the coast, which also presents excellent conditions for wind power, especially on islands. In such cases, the system can work completely independently in regions without stable or any electrical network, as well as integrated into a public net (Hensel and Uhl 2004).

In the near future the Emirate of Abu Dhabi intends to open up wind energy as local natural energy resource. The company Synlift Systems, Berlin, was authorized to evaluate the cost effective use of wind energy in selected regions of Abu Dhabi. Developing and implementing of wind energy applications were described by Lindenmann (Lindemann 2004).

The wind/diesel powered desalination plant is equipped with a pre-filtration with reverse air cleaning for open intake, particularly often used in the Gulf region. The sea water is then fed to a biofilter, installed to reduce the increased content of organics in the feed water primarily in the algae bloom time in the Gulf. A reverse cleaning filter is followed by a low energy ultrafiltration plant, which ensures proper functioning of the reverse osmosis membrane. When the Gulf water is processed, the reverse osmosis membrane recovers approx. 30-35 % of the feed water as a permeate. To prevent biofouling of the membranes the feed water is disinfected.

The operating costs of the energy supply in case of wind/diesel powered seawater desalination amount to approx. 5.4 kWh/m^3 of drinking water. Using a tariff of 0.065 EU/kWh this corresponds to 0.35 EU/m^3 d.w.. Comparingly, the energy costs of diesel powered sea water desalination as off grid solution amounts to approx. 1.2 EU/m^3 d.w.. Additionally, operation costs should have to be accounted. The operating costs for fresh water production are estimated to be 0.74 EU/m^3 d.w. (Lindemann 2004). This leads to a total of 1.09 EU/m^3 d.w. for the wind/diesel powered system and of 1.94 EU/m^3 d.w. for diesel powered desalination.

5 Discussion

5.1 System requirements

In general, POU systems which are common in developed countries, are based on RO with multistage pretreatment. These are complex technologies which require maintenance, annual replacement of pretreatment modules and feed water with good quality and stable characteristics. This kind of systems, being sensitive to the feed water parameters (see 4.6.3.), are not able to cope with spatially or seasonal variability in feed water quality. Besides of this, initial and operational costs of these systems (see 4.5., 5.2.) are much too high for most population of developing countries. Therefore, these POU technologies are considered to be not suitable for the market of POU systems in developing countries.

On the other side, systems available and proposed by NGOs or local research institutions for rural or urban areas in developing countries, are often relatively simple (for example storage in tanks with chlorination, SODIS, ceramic filters, solar pasteurization etc. described above in (4.3., 4.5.)). These systems, when applied correctly, may assure water which is probably microbiologically safe. Normally they are cheep, easy to maintain and affordable to local population. But their wide acceptance is often limited due to small productivity, tedious performance and inconveniency. Furthermore, the taste, smell and color may not be attractive in many cases and often no barriers for pollutants are provided. In some cases, when the technologies are applied incorrectly (e.g. overchlorination or lacking sunlight in SODIS performance), this could lead to appearance of additional contamination and risks. These simple systems can provide a short term solution for improving water quality in developing countries, but mostly they are not able to provide improved access to necessary amounts of safe water. The economical growth of the developing and transition countries followed by increasing public concern in water quality and increasing affordability requires long term sustainable solutions. Advanced technology, such as membrane technology, are in principle suitable for application on a small scale (modular design) and can provide constant water of good quality.
However, the system has to be robust, almost maintenance free, modular in size to fit a wide range of water demands, and it must be able to perform stand-alone operation (Schaefer 2005). The existing membrane systems still are not able to fulfill these requirements, while they cannot be maintained in remote area, do not operate for extend periods and need qualified supervision. This mean that further work is needed to develop robust and almost maintenance free systems and integrate such treatment systems in a socially, economic and environmentally sustainable way.
In addition to treatment, the distribution of safe water to poplulation and storage in the individual households is a critical factor as it has a large impact of the water finally consumed. However, this aspect is not the scope of this review and therefore will not be discussed in detail.

5.2 Costs

WHO categorizes costs for POU systems as low, medium and high on a worldwide basis including the poorest people. Categories for annual household cost estimates in US dollars are less than $10 for low, $10-100 for moderate and >$100 for high. Clearly this cost categories will be different for different economic situations in different regions and countries of the world (WHO 2002). In general the affordability of water treatment technologies is the lowest in rural areas of developing countries, and is higher in urban areas of developing countries and rural areas of transition countries. Often, in urban areas of transition countries the middle class is able to afford the systems used in developed countries, while the concern of water quality is high. The costs normally include initial costs needed to buy, deliver and install the system and operational costs - costs of reagents, energy and service if needed, and maintenance and replacement of parts of the system.

In developed countries, e.g. USA the tabletop or flow-through units typically cost less than US$100. Generally these units can be purchased at hardware and department stores. POU devices that are installed under the sink that supply water to a third faucet or are in-line can cost up to several hundreds of dollars, but these units will typically include several technologies to remove a broad spectrum of contaminants from several hundreds of liters of water before maintenance is required. The maintenance costs are relatively high, filters and membranes have to be replaced within 6-24 months, leading to total maintenance costs in the range of 85-135 $ (see 4.6.3). It should be considered furthermore, that these systems are designed to function with clean water, so in the case of raw feed water, pretreatment costs should be added. Furthermore, the systems rely on pressure from the tap water, and for areas where no pressurized water is available, the costs for pumping infrastructure and energy have to be added.

POU units that treat tens of thousands of liters of water for an entire household can cost in excess of US$1000 depending on the technology selected (Craun, Goodrich 1999). As discussed in (4.6.3) the operation costs of available membrane-based POU systems are in the range of 1-2 EU/m^3 even for systems operated on renewable energy sources. As the minimum required drinking water amount is 10L per person and day, the annual costs exceed the annual budget even for the "richest" group of people defined by the WHO (>100$ per year).

5.3 Situations where POU membrane based systems are relevant

(A) Developed countries:

In urban and peri-urban areas of developed countries (Situation A1), POU/POE membrane based systems have already found and still can find application for additional water treatment. In some cases, insufficient water quality may be the reason for purchase, but also specific requirements of consumers can be the reason in cases where the water quality is impeccable. A large range of membrane-based systems is available on the market for this kind of applications.

In rural areas of developed countries (A2), especially in remote areas, tap water may not be available and in such cases POU systems find application, and also membrane based systems are in use. The main difference however with the systems for tap water treatment (*A1*) is the fact that the feed may contain much higher concentrations of all matrix components and also the composition may vary in time. Therefore, such systems are often designed tailor-made, which makes them relatively expensive.

(B) Transition countries:
In urban and peri-urban areas of transition countries (B1), POU/POE membrane-based systems are being used increasingly. The reason of this application lies often in the unreliable quality of available tap water, not only with respect to hygiene, but in some cases with respect to taste, color, turbidity etc. In some areas of transition countries, also the quantity of available water may be insufficient, or periods without water supply from the tap urge to use alternative water sources with decentralized treatment systems. Although systems as described under (*A1*) are available on the market, these systems might prove too expensive especially for the low-income range of the population.
In rural areas of transition countries (B2), the situation is largely comparable to the situation in those areas of developed countries (see above).

(C) Developing countries:
In urban and peri-urban areas of developing countries (C1), the present use of POU/POE membrane systems is mainly limited to the rich part of the community and in special situations (e.g. Hospitals, high-class Hotels) where a reliable water quality and quantity is required or desired.
Potential for use is available also in urban areas where water supply is not available (C1.1). However, in such situations, a reliable centralized supply finally will be a cheaper and more sustainable solution and thus, POU/POE systems in such situation are mainly seen as a temporary solution.
In cases where the quantity of water is insufficient (C1.2), this often leads to local exploitation of alternative water sources (e.g. rain water, wells). Especially in the case of shallow wells and uncontrolled collection and storage of rain water, the quality of such sources may be unreliable and treatment is required.
In many cities in developing countries where a central supply exists, the quality is not reliable (C1.3). In these cases POU/POE can find application. This leads to a situation of dual water supply, where the supplied water is of sufficient quality for all purposes except consumption, and locally treatment systems are employed to produce a water quality suitable for drinking. For these situations, an improved central supply is expected to be a more durable and overall cheaper method, and then POU/POE systems could be considered as a temporary solution. However, in cases where the introduction of centralized treatment systems is hindered due to political/economical conditions, POU/POE systems also may provide a more structural solution.
In rural areas of developing countries (C2), the situation again is comparable to that of the transition and developed countries. Differences exist in the acceptable level of costs for POU/POE systems and the ability of the local community to safeguard maintenance and control of these systems.

For all of the situations indicated above, in principle different types of POU/POE systems can be applied. Three main advantages of membrane-based systems in comparison to other systems can be identified:

I. Membrane systems have a modular design. This implies that systems can be applied on each scale from one single household with no upper limit of capacity. Furthermore, expansion of existing systems can be carried out relatively easily by adding membrane units (provided that the systems are designed to allow this).
II. Membrane-based units can be operated not only by a range of different energy sources, including mechanical energy and hydrodynamic energy (pressure from the tap or from elevated reservoirs). This enables application independent from expensive and/or sensitive utilities such as electricity or solar energy panels.
III. Membranes are absolute filters, i.e. they provide high log-removal of pathogens such as bacteria, viruses and parasites.

Also disadvantages of membrane systems in comparison to other POU/POE systems exist. In view of the broad range of other systems available, these disadvantages can not be generalized easily. A detailed comparison of technologies is described in chapter 4.

5.4 Application of membrane POU systems: Research and development needs

From the discussion in the chapter (5.3), the following conclusions concerning development needs can be drawn:
(A1): Many systems are available, not much development is needed.
(A2): Custom-built systems are applicable which are relatively expensive, but in most cases are still affordable:

(B1): Available systems as described in (A1) may be affordable in some cases, or too expensive in other cases.
(B2): Custom-built systems are applicable which are too expensive for most situations. A need for cost-effective systems which can cope with a wide range of water qualities exists (Broad Feed Water Quality Systems (BFWQ)).

(C1) Available systems as described in (A1) are not affordable for the largest part of the populations.
Furthermore, this kind of systems is only suitable for situations with sufficient quantities of central water supply having a relatively constant quality (a special case of (*C1.3)*). In all other cases, low-cost POU/POE systems are needed which can cope with a wide range of water qualities.
(C2) Comparable to situation (B2), a need exists for low-cost POU/POE systems which can cope with a wide range of water qualities.

Membrane-based POU/POE systems are especially attractive for application in developing and transition countries because of the advantages (I-III) described above, including absolute retention and flexibility of energy sources.
The difference of the developing countries (Situation C) in comparison to transition countries (B), is not only the fact that the acceptable cost level is

lower, but also the fact that maintenance and control (M&C) are very critical (e.g. replacement of membrane modules). In many cases, structuring M&C by authorities or supervised NGOs is required because the population does not have funds for M&C or because the level of education is not sufficient to supervise relatively complex and sensitive systems. Because of these complexities, low-maintenance systems are preferred in general.

Thus, it can be concluded that POU/POE systems have a high potential for application in selected situations especially in the developing and transition countries, and that membrane-based are attractive in these cases. For these situation, the following research needs can be identified:

1. Systems which are able to cope with a wide range of feed waters ("BFWQ Systems")
2. Low-cost systems (both with respect to investment costs as to operation costs)
3. Low-maintenance systems

Ad (1): As discussed before in detail, pretreatment systems are generally installed in order to protect the membranes. For the BFWQ systems, the requirements on pretreatment are more pronounced and the present multi-purpose systems are not suitable. Thus, suitable pretreatment systems should be developed. Another strategy is to develop membrane systems which are not sensitive to fouling. The Swartz Fiber Cloth membrane is an example of this type of systems. For a part the development of robust, BFWQ systems will result also in low-maintenance systems, for example the life-time of membrane modules can be expanded by proper pretreatment. However it must be considered a basic amount of maintenance and especially control/supervision is required in all situations.
Ad (2): The costs of POU/POE systems are not only dependent on efficient design, but also on the scale of production. In order to reach a situation of sufficient production volumes, transition scenarios including financial support models may be necessary.

Generally, the literature review has shown that a scientific background of membrane POU systems use is missing. Most of the POU membrane based systems have been created similarly to industrial or laboratory devices. Dedicated investigations on membrane fouling processes in POU/POE systems, influence of feed water quality on pretreatment performance could not be identified in the literature. This hinders development of these systems in the directions described above.

6 Conclusions

In comparison to centralized treatment systems, POU systems are suitable for situations where water distribution systems are lacking (both in urban and in rural areas of developing and transition countries) and in cases where the amount of available water is insufficient. In some cases (e.g. urban areas with existing distribution systems but insufficient water quality), improved centralized treatment is expected to be more efficient and cheaper than widespread POU/POE systems, but the latter systems could be a temporary solution in these cases.

A range of different POU systems are available nowadays, but the design and cost of most systems are developed for application in developed countries with controlled feed water qualities (pre-treated water and availability of tap pressure). Also membrane POU systems are available on the market, and most of these systems consist of a pretreatment step (generally AC or Microfilter), a membrane module and a post-treatment step (generally AC). Relatively high costs are associated not only with the investment of these systems but also with maintenance such as replacement of cartridges.

For application in developing or transition countries, the cost level is in general not acceptable. Furthermore, the source water quality can differ regionally as well as seasonally, and the POU/POE systems should be able to treat this kind of waters. Another critical factor in transition and especially in developing countries is the maintenance and control. Not only the level of education of the local population may be insufficient, but also structural financial means for maintenance and control may be lacking. The solution can be found in long maintenance intervals, structuring of maintenance and control operations or a combination of both.

Thus, a need for development of POU/POE systems exists, mainly in the following areas:

- low-cost systems
- low-maintenance systems
- systems which are able to treat a wide range of feed water qualities

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