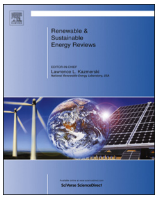
Renewable and Sustainable Energy Reviews 40 (2014) 542–556

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Renewable energy powered membrane technology: A leapfrog approach to rural water treatment in developing countries?

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ARTICLE INFO

Article history:
Received 21 June 2013
Received in revised form
22 May 2014
Accepted 19 July 2014

Keywords:
Renewable energy
Membrane technology
Water supply
sub-Saharan Africa
Cost
Water quality

ABSTRACT

Lack of access to safe drinking water remains a present concern in many developing countries, particularly in rural locations. Membrane water treatment technologies have the potential to remove microbiological and chemical contaminants reliably and simultaneously from a wide range of water sources. When powered by renewable energy, these systems are autonomous and have the ability to 'leapfrog' over installation of traditional infrastructure for electricity and water supply to reach remote communities. In this paper, current estimated costs for water, membrane plants and infrastructure are compared to indicate the window of opportunity for these exciting renewable energy powered membrane (RE-membrane) technologies. General estimated costs for decentralized membrane systems are within the range of some untreated water costs in developing countries. Specific system costs, however, are very process and location dependent. The appropriateness of a successful approach thus depends partially on careful examination of these parameters. In view of the comparisons made here, the biggest hurdle to adoption of the RE-membrane technology in a remote location may not be cost, but rather sustainability issues such as the lack of skilled personnel for operation and maintenance, service networks, availability of spare parts, socio-economic integration and adaptive capacity of communities to transfer and develop technology appropriate to local needs and circumstances.

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http://dx.doi.org/10.1016/j.rser.2014.07.164
1364-0321/

1. Provision of safe drinking water in developing countries

Renewable energy powered membrane (RE-membrane) systems are attractive decentralized water treatment options in areas without infrastructure and where dissolved contaminants render water sources unsafe [1,2]. Such technologies are suitable to treat most sources, including wastewater and seawater, to meet potable water standards and are scalable from single household to city-scale supplies. A key challenge is the lack of infrastructure in remote areas, which are often rural areas of low population density, regions affected by conflict or natural disaster, in either developed or developing countries. In fact, according to the report by the World Health Organisation (WHO) and United Nations (UN) [3]: '*more than three quarters of those who lack access to safe drinking water and basic sanitation live in rural areas.*' This is set against the backdrop where [4]: '*Alternative water systems have been used in rural areas for decades. They obviously are an option in new urban areas where no central infrastructures pre-exist, and in extra-urban urban areas.*' Such alternative supplies cover water reuse in addition to decentralized treatment. Water reuse is receiving significant attention, in particular at large scale and as a competitor to seawater desalination, but its uptake is slowed significantly by public acceptance [5]. While the urban, peri-urban and rural situations differ in population density, water governance and propensity of pollution, the country to country differences can be significant. For example a small village in rural Africa may consist of a population of about 50, while a classic Indian village may have a population of up to 5000. This emphasizes the requirement for scalable models and technologies.

Poor water quality (microbiological and chemical) is the cause of unnecessary health problems within communities [6–8]. While advanced technologies such as RE-membrane systems are technically capable to address this severe problem [9–10], the acceptance is neither as broad nor the implementation as rapid as expected. Systems rarely survive long term in such regions. In addition, it is a common perception that such technologies are too costly, too complicated and hence generally unsustainable for application in developing countries. Eskaf and Moreau [11] have highlighted the lack of financial and managerial capacity due to the higher unit costs of small systems and lower revenues and skill available in rural areas, while Bugaje noted that addressing energy availability in Africa was the key to addressing health, educational and other socio-economic problems [12].

Interestingly, the above issues are not limiting technology uptake in other markets. In the field of mobile communications technology, adaptation evolved differently. Fifteen years ago few, if any, would have foreseen the mobile phone boom in developing countries. Growth in mobile phone subscription in Africa increased between 2000 and 2011 at a compound annual growth rate (CAGR) of 41%, significantly higher than in Europe (30%) [13]. In contrast, whereas over 92% of households in the UK had a fixed phone line in 2013 [14], the African continent has the lowest coverage of fixed phone lines: just over one line per 100 people in 2011 and only growing at a CAGR of less than 3% [13]. With the mobile phone boom, the African continent has leapfrogged over the western industrialization pathway of fixed telecommunication lines, and in doing so saved on considerable investment in infrastructure. In addition, the rapid adoption of phones contributes significantly to economic development in areas such as (i) agriculture trading: receiving market prices via short message service (SMS); (ii) enabling the transfer of small amounts of money from one person to another via SMS; (iii) enabling climate change adaption by using the global positioning function of the device to map out deforestation in Malawi; (iv) training healthcare workers in rural areas of Mali via telemedicine [13], and (v) the payment of water and electricity usage in East Africa.

The success of the mobile phone may inspire a similar decentralized approach to water services in rural areas in developing countries. In remote locations that are lacking both water and electricity infrastructure and a safe water point source, installation of RE-membrane technologies could avoid the reliance on centralized treatment works. The promise of such advanced membrane systems, namely contaminant removal, modular design, technical robustness, upscale potential, was outlined by Schäfer et al. [15] and Peter-Varbanets et al. [10]. In this paper, water costs by source in developing country contexts, typical membrane plant costs and estimates of infrastructure costs are compared to indicate the window of opportunity for this leapfrog approach. The context is set by a discussion of water supply and quality in developing countries, and an introduction to membrane water treatment technologies.

Lack of safe water supply is a recognized problem in many developing countries. Globally, it is reported that 884 million people do not have access to safe, protected water sources [16]. This has a significant economic impact [17], and causes illness and death from easily preventable water-related diseases. For example, "*88% of diarrheal disease – the second leading cause of death in children younger than five years after respiratory illness – is attributed to unsafe drinking water*" [6]. Global policy supports efforts to increase coverage of safe water supply, with a target within the UN millennium development goals (MDGs): to, "*halve by 2015 the proportion of people without sustainable access to safe drinking water*" [18]. Whilst trends indicate that globally the world has already met this target, the progress of individual countries varies greatly. In particular, only 19 out of 50 sub-Saharan African countries are on target to meet his goal and rural areas lag well behind [18]. Furthermore, the issue of dissolved contaminants (including salts), that are difficult to remove, remains vastly unaddressed.

Progress of the MDG for improving access to 'safe' drinking water is measured against the number of people having access to an 'improved' water source [18]. The following are classified as 'improved' sources: piped water into a dwelling, yard or plot, public tap or standpipe, tubewell or borehole, protected dug well, protected spring, and rainwater [19]. It should be noted that this does not consider actual water quality. By definition, an 'improved' drinking water source or delivery point, "…*by nature of its construction and design, is likely to protect the water source from outside contamination, in particular from fecal matter*" [20]. There is no direct link, however, between an 'improved' water source and the quality of that source; the 'safety' of 'improved' water sources may be compromised by factors such as inadequate treatment at a centralized treatment works, recontamination in the distribution system, contamination of a well or borehole from anthropogenic sources (for example mining, farming, sewage), or the natural chemical quality of groundwaters with naturally high levels of salt or contaminants such as fluoride, nitrate, uranium or arsenic). Thus, even in cases where a community has access to an 'improved' water source, that source may require treatment to make it 'safe' for drinking. The WHO and United Nations Children's Fund (UNICEF) Joint Monitoring Programme (JMP) for water supply and sanitation notes that [16]: *"any new target set beyond 2015 will have to address water quality, which will have to be measured or estimated in a meaningful and cost-effective manner"*. This is precisely where RE-membrane systems play a key role in treating such waters to potable standards.

Indeed there has been a lot of discussion in the literature on RE-membrane technologies (see for example [1–2,21–22]). The majority of these papers focus on a review of the possible technologies, which is often weighted towards large scale installations as that is where the majority of the technical and financial data originates from. In addition, the challenge of installing and operating such technologies in small isolated communities is often not discussed.

Providing rural areas with access to 'safe' water evidently remains a major challenge, with 53% of people in rural sub-Saharan Africa still