

Research Paper

Using business models in designing market-based solutions: the case of fluoride treatment systems

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ABSTRACT

This paper addresses how business models inform viability of different fluoride treatment technologies for developing countries as well as the pursuit of financial and operational sustainability. Excess fluoride concentrations in drinking water supplies negatively impact the health of communities living in fluoride affected regions of the world by causing dental and skeletal fluorosis and other severe socio-economic problems. Given that fluoride mitigation solutions have proven elusive, we apply business model logic to compare fluoride removal technologies to examine the financial sustainability of water service provisions. We analyze the investment cost of producing fluoride safe water, the annual revenues generated, and the net benefits obtained from different technologies. Furthermore, the reduced medical costs and productivity losses averted due to access to fluoride safe water can lead to an average annual cost saving of \$67 per person. Our results validate the use of business models to help evaluate different technologies as a means of pursuing sustainable applications for safe drinking water.

Key words | business models, chemically activated cow bone, electrolytic defluoridation fluoride, Nalgonda, technological and economic sustainability

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INTRODUCTION

The global need for sustainable solutions to provide basic human needs (e.g., safe drinking water) has never been greater. As human needs mount, it is becoming increasingly apparent that entities such as governments, foreign aid and non-governmental organizations (NGOs) are unable to meet these mounting needs. Getting to viable solutions is increasingly being connected with business models to implement sustainable solutions that incentivize key input providers to the final users. A business model describes the system of interdependent activities that are performed by the firm and its partners, and the mechanisms that link these activities to each other to deliver value (Chesbrough 2010; Zott & Amit 2010). For example, Wüstenhagen & Boehnke (2006) demonstrated that barriers to sustainable energy can be addressed with innovative business models. More

broadly, it is becoming increasingly recognized that well designed business models have the potential to address prevailing global problems including sustainable development (Wilson & Post 2013).

This article focuses on the sustainable supply of safe drinking water in developing countries. It is estimated that more than 200 million people worldwide consume water with fluoride concentrations above the World Health Organization (WHO) recommended threshold of 1.5 mg/L (Amini *et al.* 2008). To address this growing problem, our purpose is to show how the use of business models can help lead to more sustainable fluoride solutions. More specifically, we address the fluoride affected water in the Rift Valley of Ethiopia as a pathway for considering the viability of such an approach throughout the developing world.

The business model is used as a tool to set up a sustainable market-based scale-up of defluoridation (fluoride removal) systems so that safe drinking water can become the norm rather than the exception in these areas. Our objectives are the following:

1. To extend the use of business models into social needs where market-based solutions and sustainability are becoming increasingly valued; we specifically address the safe drinking water issue.
2. To show the relevance of business models in evaluating alternative approaches to a given business activity; specifically to the application of defluoridation of drinking water.
3. To compare viability of fluoride treatment technologies as a business venture.

By using the business model approach, we show how one can assess and compare viability of different fluoride treatment methods. This has significant implications for financial and operational sustainability. In discussing the business model logic and its principal components, we are able to show relevance to the operations of safe water supply services where unsafe levels of fluoride are a major problem. We explicitly address fluoride challenges instead of other water contaminants because fluoride is one of the most difficult contaminants to correct and is a pervasive problem in developing countries. This sets up the viability of business models in addressing fluoride challenged areas as a template for many other safe drinking water issues.

BUSINESS MODEL LOGIC

Business models seek to address fundamental questions such as – who are the customers, what do they value, how does the business deploy its assets, and how value can be delivered to the customer at an appropriate cost (Osterwalder *et al.* 2005; Zott & Amit 2010). Business models consist of both a quantitative assessment of how the business makes a financial return and a narrative of how the business works. Sustainability of a business depends on the quality of services it offers to the customers, its focus on addressing the unmet needs, value-additions, and

the ability to link technical and socio-economic issues relevant for delivering value to customers (Chesbrough 2010).

While business models were first explicitly applied to electronic commerce, they are now utilized in most industries including markets in developing countries (Brown *et al.* 2009). By extension, our assumption is that applying business model logic to safe drinking water needs in developing countries has great potential. The development of business models and the creative thinking that they encourage are likely to be critical for the development of sustainable services involving basic human needs in developing countries. The use of business model logic can be very instrumental in better articulating how basic human services and needs, such as water, can be met in a more sustainable manner.

Business models for safe water supply services

Small-scale private water service providers are emerging as common and reliable deliverers of water in areas with significant population. With the efficient utilization of resources, private water treatment systems are able to achieve sustainability and make an adequate return to continue with services (Kariuki & Schwartz 2005). However, publicly owned services tend to be intermittent in their provisions of water and they usually need subsidies to continue operations (Guidthai 2008). The delivery of water purchased from boreholes and water kiosks to end users has been documented in places such as Onitsha, Nigeria (Whittington *et al.* 1991), peri-urban areas of South America, urban areas of Sub-Saharan Africa (Solo 1999), and Mumbai, India (Angueletou-Marteanu 2007). Private water service providers are increasingly proving effective for areas that historically have not had access to safe water. By extension, we assume that suitably designed business models can help address existing problems related to safe water supply services, even in the more rural areas of developing countries.

Significant efforts have been made to examine and reform water delivery in population areas of developing countries over the past several decades. Unfortunately, only very limited attention has been focused on rural water supply services and virtually no attention has been given to the scaling of the defluoridation of water.

Sustainability of safe water supply schemes is constrained by social, technical, financial, institutional and environmental issues (Brikké & Bredero 2003). Some of the common problems faced by safe water supply schemes in Ethiopia include availability of spare parts and chemicals, capacity for scheme operation and management, tariff collection, and water quality issues (Israel & Habtamu 2007). As a result, the non-functionality rates of the developed safe water supply schemes are high (Abebe & Deneke 2008).

This paper argues that business models can help identify and correct the prevailing sustainability challenges faced by safe-water supply services. More specifically, since safe-water technologies are central and the early step in addressing this huge need, we address the technology side of business models in seeking sustainability socially and economically. This is foundational to the development of sustainability of the safe-water supply services.

Drinking-water fluoride concentrations in the Ethiopian Rift Valley range from 1 to 33 mg/L with an average value of 5 mg/L (Haimanot *et al.* 1987). Beyond dental and skeletal concerns, fluorosis has significant socio-economic impacts stemming from skeletal fluorosis (Apambire *et al.* 1997; Frank *et al.* 2011). Moreover, the prevalence of fluorosis and the related health problems is very prevalent and has stigmatized entire villages (McKnight *et al.* 1998; Frank *et al.* 2011). One community-based survey revealed 65.7% skeletal fluorosis among adults (Tekle-haimanot *et al.* 2006). While our experience here is connected to the fluoride-affected areas in the Rift Valley of Ethiopia, the implication of this paper will likely have considerable applicability throughout the developing world. The business model concept is used to set up a sustainable market-based scale-up of defluoridation systems so that safe drinking water can be more widely obtained.

DEFLUORIDATION TECHNOLOGIES

Among various technologies developed and implemented to remove excess fluoride concentrations from drinking water supplies, the Nalgonda and bone char techniques have most commonly been implemented in developing countries such as Kenya, Tanzania, Ethiopia and India (Ayoob *et al.* 2008; Frank *et al.* 2011; Osterwalder *et al.*

2014). The Nalgonda technique, the process of aluminum sulfate-based coagulation-flocculation-sedimentation, was developed and adapted in India for fluoride removal. The cow bone-based treatment system uses thermally treated cow bone (bone char) for fluoride removal. However, the low fluoride removal capacity of bone char needs further enhancement. Recently, a high fluoride removal capacity chemically activated cow bone (CAB) media has been developed by Yami *et al.* (2016). A pilot study conducted in the Rift Valley of Ethiopia by the University of Oklahoma's Water Technology for Emerging Regions (WaTER) Center in summer 2014 and 2015 indicated that CAB had about four-fold higher fluoride removal compared to bone char. Electrolytic defluoridation (EDF) systems use aluminum electrodes that release Al^{3+} ions by an anodic reaction with subsequent aluminum precipitation; the fluoride removal occurs at the precipitate surface and settles out of solution with the precipitate. In this study the Nalgonda, CAB, and EDF techniques were considered for comparison using business model tools.

Challenges faced by existing defluoridation systems

Very limited effort is currently focused on addressing the fluorosis problems in developing countries (Frank *et al.* 2011). For example, defluoridation of drinking water in the Ethiopian context has been impractical because it is also expensive, technically unattainable by technologies evaluated, and unsustainable for large populations. However, defluoridation systems can be considered at the household and small community levels. Defluoridation systems in the Wonji-Shoa Irrigation scheme in Ethiopia used activated alumina which was expensive and had logistical constraints with operations and maintenance (Tekle-Haimanot *et al.* 2006). Reasons for poor sustainability of past fluoride treatment systems include the lack of capacity to manage defluoridation systems, lack of chemical supply chains, high cost of chemicals, limited financial management skill, and lack of skilled labor to install and operate the treatment systems (Bregnhøj 1997; Brunson *et al.* 2013). In addition, there is no engagement of private sectors in the defluoridation processes. As a result, the fluoride removal technologies developed thus far have not proven sustainable.

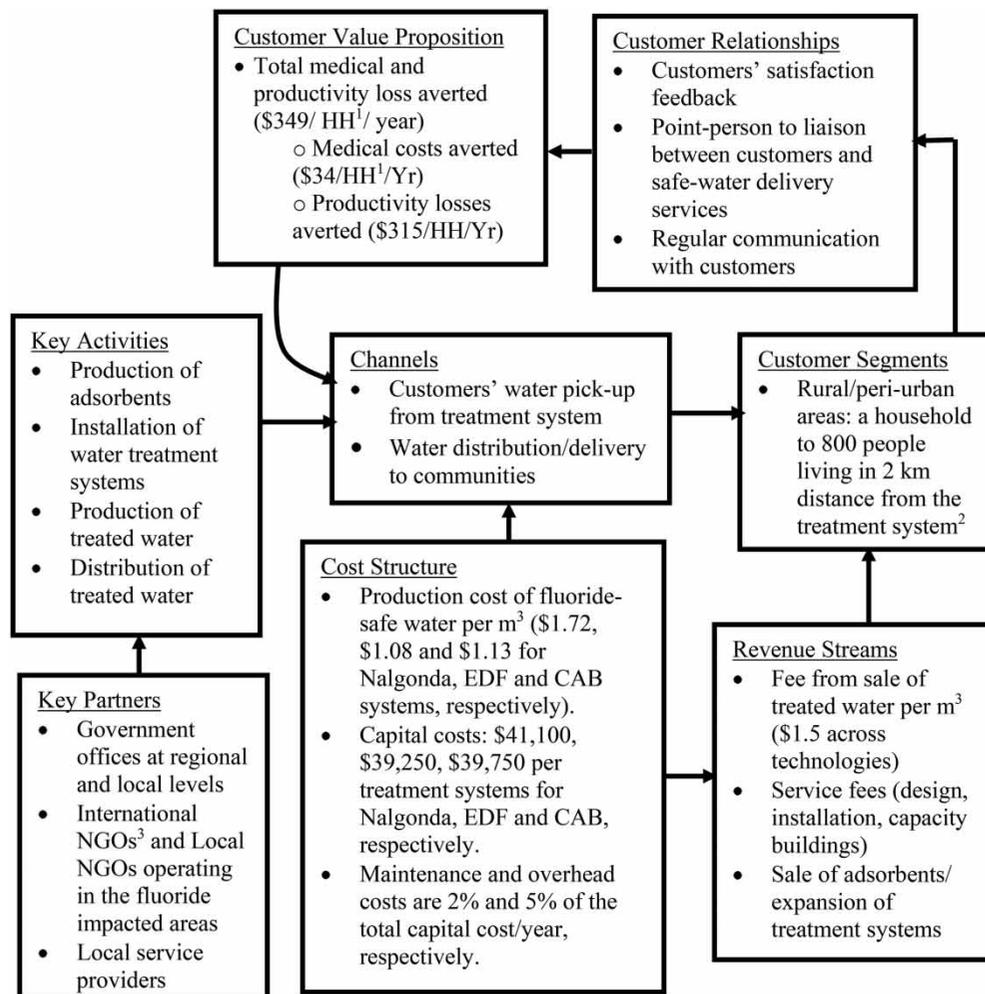
Business model for defluoridation of drinking water

The defluoridation technologies considered in this study are the Nalgonda system (uses aluminum sulfate and lime), EDF (uses aluminum electrode), and CAB (uses cow bone activated using acid and base chemicals). The business model proposed for fluoride removal from drinking water supplies (Figure 1) is expected to help entrepreneurs evaluate where the challenges are with each water technology and which ones are the most likely to achieve sustainability.

In this study, five principal components of business models are considered and discussed.

Customer value proposition

Value proposition is the value created or the benefits offered to customers (Chesbrough 2007). Fluoride removal technologies in developing countries may provide substantial cost saving advantage through averting costs incurred due to the negative health impacts associated with excess fluoride



Note:
¹ HH stands for household
² The East Shewa Zone (where defluoridation systems are currently installed) average population density of 181.7 persons/km² (CSA -2005 National Statistics, Table B.3 & B.4) was used to estimate the customers
³ NGOs stands for non-governmental organizations

Figure 1 | Proposed business model for provision of fluoride-safe water services.

concentrations in drinking waters. Communities living in developing countries are exposed to dental and skeletal fluorosis thereby incurring medical costs despite their meager income. Furthermore, crippling skeletal fluorosis exposes communities to wage and productivity losses due to restricted mobility.

The proposed business model thus provides findings from the analysis made on cost savings that can be achieved in providing fluoride-safe water to the communities. Based on this analysis, the fluoride removal technologies provide an annual average cost saving of \$349 per household due to averted medical cost and productivity loss (Figure 1 and Table S1; Table S1 is available with the online version of this paper).

Customers

The target customers are women, men and children (11 million people) living in the Rift Valley of Ethiopia and beyond. Additionally, public institutions such as schools and health posts are among the target customers. The proposed customers for the fluoride treatment systems are rural and peri-urban areas with a population ranging from one household to 800 persons living within 2 km of the treatment systems.

Cost structure

Costs include key activities such as manufacturing and installation of components of defluoridation systems, production of adsorbents, distribution of adsorbents and/or treated water, and other marketing and customers' capacity building costs.

Revenue generation mechanism(s)

Revenue refers to how the firms are compensated for the value offered sustainably (Lindgardt *et al.* 2009). The revenue generation mechanism in this business model is the fee collected from the sale of fluoride-safe water and adsorbents to the customers, and expansion of treatment systems into adjacent communities. Additional revenue is expected to be generated from services costs such as design, installation, and capacity building training offered to customers and local government offices.

Value network and strategy to remain competitive

A value network analysis is a means to evaluate and improve the capability of a business to convert assets into other forms of value to realize greater value (Allee 2008). Continuous innovations in a business model, considering changing markets, technologies, and legal structures can help achieve advantages by creating unique and hard to replicate products and services. Further, correct design of business model, implementation and refining are key factors in success and sustainability of businesses (Teece 2010). To remain competitive, the business model strategy is framed around offering sustainable services through provision of safe-treated water which meets the WHO Standards of 1.5 mg fluoride/L guideline value by supporting local government offices and communities to participate in monitoring and evaluation of the water quality.

The planning of the defluoridation systems envisages working and aligning with existing government and international and local NGO plans to expand safe water supply services to the community. Identification of additional funding sources besides the government, such as local and international NGOs, is important. Suppliers of raw materials/inputs and key partners, including private firms, will be identified and capacity building training will be provided to enhance their engagement in the expansion of defluoridation systems. A central adsorbent production facility will be established by a private firm(s). Local service providers participate in supply of raw materials and chemicals. Water distribution will be conducted by trained local service providers at the water point/kiosk. Local donkey/horse carts, bajaj (three-wheeled motorcycle), and small truck owners participate in the distribution of treated water to communities living far from the water point/kiosk.

Building blocks

The following building blocks and assumptions were made in development of the business model:

- Cost of infrastructure development, i.e., well development, installation of casing and pump, and electromechanical equipment that are common to the Nalgonda, EDF and CAB-based systems were not

considered in this analysis/comparison. These costs were assumed to be covered by the government and/or NGOs.

- Maintenance or replacement cost for main systems components such as wells, pumps and generators were assumed to be covered by the government and/or NGOs.
- \$1.5 per m³ of treated water was considered uniformly for all the three technologies as a water tariff to determine the total revenue generated from the sale of treated water based on the discussion made during summer 2014 with the communities living in the Rift Valley of Ethiopia on the affordability and willingness to pay.
- Routine maintenance cost was assumed to be 2% of the water treatment system cost.
- Operational costs include chemicals, labor cost (salaries, per diems and systems washing and replacement of chemicals), fuel, and overhead cost of firms responsible for operating the safe-water supply systems. Overhead costs were assumed to be 5% of the total water treatment systems cost.
- Dodo Wadera, Woyo Gabriel and Berta Semi communities in the Rift Valley of Ethiopia were considered as target communities in this study (Table S1), using data from these communities to set up a value proposition, and analyze costs incurred in the water treatment processes, and corresponding revenues generated from the proposed safe-water supply systems.

RESULTS AND DISCUSSION

Results

Figure 1 shows the business model developed to address the prevailing problems of fluoride treatment systems in developing countries and beyond. Table 1 shows comparison of three fluoride removal technologies, namely Nalgonda, EDF, and CAB, using economic criteria and the business model concepts. The Nalgonda, EDF, and CAB systems have an average production cost of \$1.72, \$1.08, and \$1.13 per m³ of treated water, respectively (Table 1 and Table S2; Table S2 is available with the online version of this paper). It can be observed from Table 1 and Table S3 (available online) that the total revenue generated from the sale of treated water for each system is \$9,855. Cost of production of treated

Table 1 | Economic criterion for comparison of defluoridation systems (see supplemental data for detailed calculations)

Description	Fluoride removal technologies		
	Nalgonda	EDF	CAB
Production cost of treated water (\$/m ³)	1.72	1.08	1.13
Total cost of production of treated water (\$/year) per treatment system	11,300	7,100	7,400
Total revenue generated from sale of treated water (\$/year)	9,855	9,855	9,855
Net profit per treatment system (\$/year)	(1,445)	2,755	2,455
Considering 50 treatment systems operated per year, net benefit (\$/year)	(72,250)	137,750	122,750

water per year is \$11,300, \$7,100 and \$7,400 for Nalgonda, EDF and CAB, respectively (Table 1 and Table S3). A total cost saving of \$349 per household (HH) per year (\$34/HH/Yr and \$315/HH/Yr for medical and productivity losses averted, respectively) can be achieved due to the use of fluoride-safe water (Figure 1). Table 1 shows a net-profit per year of (\$1,445), \$2,755, and \$2,455 for Nalgonda, EDF and CAB, respectively. Table S4 (available online) shows a comparison of the three fluoride treatment systems: Nalgonda, EDF and CAB using technical, economic and operation and management aspects. The comparison of the performance of these treatment technologies is made based on the analysis of the information collected from field works in the Rift Valley of Ethiopia and literature study. The data used in this comparison are summarized in Table 1 and Table S4.

Discussion

This study shows that EDF and CAB are more cost effective than the Nalgonda system due to relatively lower production, installation, and operation and management costs of these systems. Furthermore, the EDF and CAB offer significantly higher net annual benefit (profit) than the Nalgonda system (Table 1). The EDF and CAB have better fluoride removal capacity, and less daily operational requirements than the Nalgonda system. Additionally, the EDF system produces much lower sludges compared to

the Nalgonda system, and CAB media does not produce sludge.

Currently, communities in the Rift Valley of Ethiopia typically pay \$1 per m³ of water at the water point despite the fact that the treated water does not meet the WHO guideline value of 1.5 mg fluoride/L (WaTER Center baseline survey, 2014). The baseline survey additionally indicated that communities have high demand for fluoride-safe water and are willing to pay more for fluoride-safe water; their ability to do so is reflected by the observation that they have been paying up to \$4 per m³ from distant sources when water is not available in their area. The profitability of a fluoride-safe water system coupled with the averted medical and productivity losses may raise government interest to support expansion of fluoride treatment systems and also attract private firms to participate in the adaptation of the business model.

The existing fluoride-related health problems and poor sustainability of treatment systems highlighted by Bregnhøj (1997) and Brunson *et al.* (2013) are the main drivers for business model entrepreneurship opportunities for defluoridation of drinking water identified in this study. Comparisons of defluoridation systems of drinking water were performed using the business model as a tool to help identify technologies that can be sustainably utilized by the local community. Socio-cultural aspects, customer demand, marketing and distribution, and access to financial sources were given due consideration in comparing the viability of defluoridation systems to deliver value in line with Chesbrough (2010). The business model developed in this study clearly stipulated the partners involved, and identified key resources leading to success, customer segments and costs associated, and the revenue generated from the fluoride-safe water supply services. The comparison of the business models is made considering cost savings achieved due to access to fluoride-safe water, cost of water treatment, annual revenue and benefits generated.

Business models focus attention on the potential of ventures that will be responsible for the production of treatment systems in partnership with local service providers, installation of the system, and treatment of fluoride impacted water, distribution of treated water, and overall operation and management of treatment systems (Figure 1). Business models bring together a system of interdependent activities to

deliver value as developed by Chesbrough (2010) and Zott & Amit (2010). This study demonstrated that a business model is a useful tool to address the prevailing challenges encountered by safe-water supply services. Business models can help develop and expand safe-water technologies that strive to realize both social and financial returns, and thereby ensure sustainability of the safe-water supply services.

Understanding the existing challenges, working with local government, NGOs and communities, and involving academic and research institutions will help facilitate scaling up of a market-based solution to the existing safe-water supply crisis. The private sector/local service providers play a significant role in the scale up of defluoridation technologies by actively engaging in production and installation of treatment systems, and supply of equipment and chemicals. Additionally, the private sector/service providers can produce adsorbents, treat fluoride impacted water, distribute treated water and undertake operation and management works. However, incentive mechanisms to private sectors (e.g., provision of tools such as plumbing, masonry and carpentry) need to be put in place in order to maintain their continuous engagement in scale up of the treatment systems. Capacity building to local private firms, i.e., technical, financial and business management are also key in sustaining the business. We also suggest that governments concerned with safe-water supply provisions need to develop policies that can enhance participation of private sectors in expansion of defluoridation systems, e.g., provision of credit mechanisms.

CONCLUSIONS AND RECOMMENDATIONS

This study indicates that significant cost savings can be achieved from the fluoride-safe water service provision due to the medical costs and productivity losses averted amounting to up to \$349 per household per year. We have shown how the business model can be an effective tool in evaluating different technologies for the provision of fluoride-safe water supply services by solving the existing constraints of equipment and chemicals supply for defluoridation systems. The inclusion of business model logic in this domain also brings attention to technology and economic sustainability

issues for those involved with getting safe water to end-users. By comparing the viability of the various treatment technologies for fluoride removal, we show how the business model can be used as a tool to examine differences. In this study, EDF and CAB-based fluoride treatment systems produced fluoride-safe water at lower cost and more manageable maintenance, and generated higher profit compared to the Nalgonda system.

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