> > PROJECT BRIEF

This is part of a series of project briefs discussing the activities, research findings, and field experiences of PATH's Safe Water Project.

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Developing the Smart Electrochlorinator:

A Low-Cost Solution to Safe Water for Small Communities

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Mercy Corps engineers test the SE200 in the field to evaluate its appropriateness as a community water treatment solution for neighborhoods in Zimbabwe that suffer periodic cholera outbreaks caused by poor water quality.

Introduction

Safe water is essential to good health. Simple drinking water interventions can reduce the rate of diarrheal disease by one-third to one-half,[1] which could lead to countless lives saved. Diarrheal disease kills more than 5,000 children each day.[2] It is the second-leading killer of children under five.[3] The World Health Organization estimates that 1.8 million people die each year from diarrheal disease—much of which can be attributed to unsafe water.

In industrialized countries, large-scale water systems with established infrastructure deliver safe water directly into homes. In developing nations, by contrast, water often comes from unsafe and inconvenient sources. More than 880 million people worldwide get their drinking water from unimproved sources, including lakes, rivers, dams, springs, and unprotected dug wells; over four-fifths of them live in rural areas.[4] Those who have access to safe sources often find their water recontaminated[5] during transport, storage, and handling.

With support from the Laird Norton Family Foundation, PATH began investigating ways to increase access to safe water at the community level. Community water treatment systems are an effective and efficient way to:

- Provide safe water to the very poor at an affordable price.
- Take the burden of water treatment off the individual.
- Allow communities to take ownership of their drinking water, ensuring its safety.
- Potentially create income opportunities for local entrepreneurs.

Treating water at the community level permits the use of high-performance technologies that may be too expensive or too complex for household purchase and operation but that can effectively treat larger quantities of water at a low cost per liter. Community water solutions may also bring social influences to bear on residents and encourage lasting changes in household water storage and handling behaviors, while ensuring water quality and safety for the entire community. Lastly, community water treatment systems enable commercial water vendors, who are an increasingly important source of water in the developing world, to bring their customers safe, treated water.

In low-resource settings, however, few commercial water treatment solutions are available for small communities. Rather, existing solutions are clustered at two ends of the spectrum. On the one hand, there are relatively large water treatment systems that require substantial capital investment and have high operating costs. On the other hand, there are relatively low-cost household water treatment products, such as filters and disinfectants, but these require fundamental changes in household routines and are not affordable for the poorest households.

Developing an appropriate technology

Effectiveness against waterborne disease is a prerequisite for any water treatment technology. For small-scale community systems it is equally important to consider a technology's financial, technical, and management demands. Experience shows that community water projects in the developing world often fall into disrepair and disuse after encountering maintenance, financial, or managerial problems.[6] The sustainability of community water systems depends not only on selecting an appropriate technology, but also on developing a viable operating model to implement it—whether it is a for-profit business model or a nonprofit community management model.

Appropriate technologies for small community water treatment systems must be effective, simple to use, and robust, with minimal set-up and operating costs and limited operational and maintenance requirements.[7,8,9] Ideally, they should not require many people or much training to operate nor require a connection to the power grid. Ready availability of supplies and spare parts is also important. Cost is a key factor: to be sustainable, water treatment systems cannot cost more than a community can afford or is willing to pay for safe water.

Based on these criteria, electrochlorination is a promising core technology for community water treatment. Disinfecting water with chlorine has been proven effective against bacteria, viruses, and some protozoa; the process is relatively quick and easy; and it has been successfully employed in many developing countries to make water safe for drinking. Residual chlorine left in the water also provides some protection against recontamination from common household practices, such as storing water in open containers or dipping hands or utensils in storage containers while drawing water.[10]

While there are small-scale electrochlorinators that require technical expertise in process control, frequent measurements, and completion of mathematical formula, there are also ones that make limited technical and financial demands—ideal for developing-world, small-community settings. Most small-scale electrochlorinators require only a 12-volt battery, table salt, and water to create a sodium hypochlorite solution that is suitable for treating drinking water. They do not require consistent water pressure to work or a direct connection to the power grid. These advantages outweigh some admitted drawbacks to chlorination, which include lack of effectiveness in turbid water, the need for careful dosing, and a taste and smell that some consumers dislike.

PATH partnered with Cascade Designs, Inc. (CDI)—a Seattle-based company with extensive experience and expertise in assessment of water treatment technologies, research and development, design, and manufacturing—and selected a patented electrochlorination technology from the MIOX Corporation. The underlying technology has been used in the outdoor/backpacking market and in military applications for challenging environments.

Together, PATH and CDI developed a prototype smart electrochlorinator

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Feedback from the operators of this water kiosk in Korogocho, Kenya, was used to develop a second-generation prototype of the SE200.

with a simple user interface and low power requirements. The smart electrochlorinator includes a single push button to operate the device, a run light indicating the device is working, and two warning lights indicating that the salt or battery is low. A car battery provides the power source. Each 90-second run of the device creates enough chlorine solution to treat 20 liters of water, which is a common size for water collection vessels in East Africa.

Initial field tests for the smart electrochlorinator

To test this initial prototype, PATH worked with the Redeemed Gospel Church, a 30,000-member church that runs community health and education programs outside Nairobi, Kenya. A sales kiosk, a water tank, and the smart electrochlorinator were installed in the slum community of Korochogo. Community members were trained to operate the device, dispense the chlorine solution, troubleshoot problems, and perform quality control checks on chlorine dosing. Sales of safe water and chlorine solution to community members began in December 2008. The price was set at 1 Kenyan shilling (equivalent to about US$0.01) per 20 liters of treated water, matching the price charged by other local water vendors. In addition, PATH worked closely with a local entrepreneur, Caroline Otego, to test the prototype in her water kiosk in Kisumu, Kenya.

In both instances, the prototype device proved to be robust, effective, and easy to use in the field. After training, local workers performed the procedures consistently and correctly. Operating costs were low—about US$0.50 per capita annually for raw materials and electricity—making the technology affordable even for extremely poor communities. After six months of experience, the workers provided feedback on various aspects of the design, including the device's capacity—they wanted to be able to treat larger batches of water per cycle.

Developing the Smart Electrochlorinator 200

In 2009, with the feedback from the Kenya field trials and thanks to additional support from the Lemelson Foundation, PATH and CDI worked to revamp the design and develop a second-generation, higher-capacity device called the Smart Electrochlorinator 200 (SE200). The SE200 is about the size of a soda can (see photo) and takes 6 to 8 minutes to produce enough chlorine solution to treat 200 liters of water—ten times the capacity of the initial prototype. The solution can be dispensed in smaller quantities to treat different sized containers—1 standard teaspoon (5 mL) will treat

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At about the size of a soda can, the SE200 can easily be transported to any water source.

20 liters. Compared with the initial prototype, the SE200 looks more like an appliance and has clearer indicators and brighter colors. The specifications for the SE200 are listed in Table 1.

Compared with existing water treatment systems for use in developing countries, the SE200 offers many advantages in the areas of ease of use, reliability, safety, and logistics.

- The "smart" circuitry in the device measures changes in water chemistry to deliver consistent concentrations of chlorine for accurate dosing without complex process monitoring or calculations.
- The SE200 does not require steady water pressure to work or connections to a power grid.
- It is portable and can be set up at most water sources, including water trucks, boreholes, surface water sources, and dug wells.
- Treatment of water in small batches keeps the process simple. It eliminates the need to monitor the treatment process in large volumes of water.
- With chlorine available on demand, there is no need to store or transport the chemical and hence no risk of chemical degradation over time.
- There is no need to store water, which helps keep costs to a minimum.

Some training is required to learn how to operate the SE200 and to properly dose water with the chlorine solution; however, the training is not rigorous or extensive. Needed skills can easily be learned by designated community members. The instruction manual teaches operators how to make a salt solution (or brine)

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The entire SE200 system is compact and easy to transport.

Table 1. SE200 Specifications

Total factory cost target	$100
Target working life	5 years
Volume of contaminated water treated by one batch of chlorine solution	200 liters
Run time to produce a batch of chlorine solution	6-8 minutes
Free available chlorine concentration of solution	0.75%
Quantity of water that can be treated on one battery charge (12V, 80 amp-hour	40,000 liters

in a mixing bottle, connect the electrochlorinator to the battery, produce chlorine solution, correctly dose water with the chlorine solution, perform quality control checks, and troubleshoot problems.

As part of the development process, the SE200 underwent comprehensive testing to establish its functionality, robustness, durability, and treatment effectiveness. Based on the results of engineering studies and user feedback, PATH and CDI continued to refine the design to improve the SE200's functionality and manfacturability, that is, the relative ease of manufacturing the device at minimum cost and maximum reliability. Changes included adding feet and a lid to the chlorine generation unit; altering the concentration of the chlorine solution produced so that a commonly found 5-ml spoon (1 teaspoon) is the correct dose to treat 20 liters of water, and adding a measuring cup to dispense the solution. In addition, engineers selected a plastic material for the device that could stand up to long-term exposure to the sun, oxidant solutions, and daily wear and tear. The team also refined the operating instructions and training manual for the SE200 and tested both in Kenya. In addition to the chlorine generation unit, the complete system includes:

- Connections for an external 12-volt DC battery.
- A 12-volt DC battery.
- A battery charger.
- A brine mixing bottle.
- Dispensing cup and spoon.
- Operating instructions.

Field testing the SE200

Once the SE200 had been tested further to ensure that the device remained safe, durable, and effective after the redesign, the next step was to select sites for focused field trials. Field trials would gather information on the ease of use of the new design and its appropriateness in different settings, as well as test different operating models. Agreements were signed with six local implementing partners to conduct the field trials (see Table 2). They were selected for their diversity, reliability, and strategic strengths. Field trials of the SE200 took place in spring 2010 in seven countries in sub-Saharan Africa and three countries in south and southeast Asia (see map). PATH and CDI team members conducted training on the SE200 and set up field trials at multiple sites in Kenya, Ghana, and Zimbabwe. Another 25 devices were delivered for testing in Guinea, India, Mali, Nepal, Niger, and Tanzania where implementing partners conducted the training and tests.

Table 2. Locations and field implementation partners for SE200 field trials, by operating model

Location	Partner
Community water committees	
Ghana, Mali, and Niger	World Vision
ZImbabwe (Mutare)	Mercy Corps
Small business kiosks	
Guinea	Antenna Technologies and Tinkisso
India	Antenna Technologies and Develpment alternatives
Kenya (Kisumu)	Aquaya Institute
Mali	Antenna Technologies and Formations Sans Frontieres
Mali	Antenna Technologies and Aidemet
Tanzania	Groundworks
Business franchises	
Kenya (Nairobi)	Pureflow Water Solutions
Schools and community centers	
Nepal	Antenna Technologies and Environmental Camps for Conservation Awareness
Diasaster response and humanitarian assistance	
Thailand	US and Thai militaries: Operation Crimson Viper

The objectives of the field trials were to:

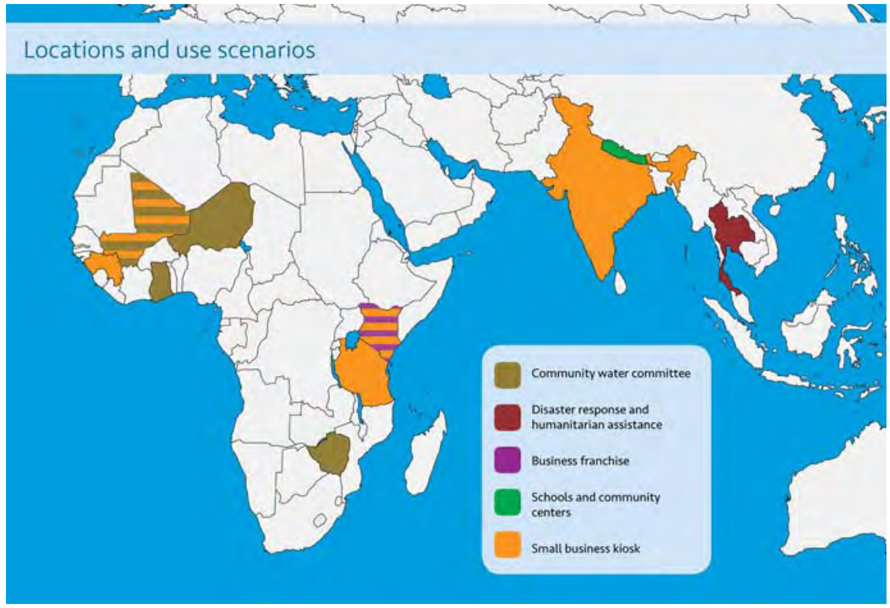
- Collect feedback from operators to inform improvements to the device and its accessories, as well as to the training materials and instruction manual.
- Validate the durability and consistent performance of the SE200 over time and in various settings.
- Understand the value of the SE200 in different use scenarios.
- Understand potential business models for the SE200.

With regard to potential business models, several operating models for use of the SE200 were tested at the different sites. For many years, most small-scale water supply and treatment systems in developing countries were installed by donors, after which the community only sometimes took responsibility for operating and maintaining them. More recently, nongovernmental organizations have begun setting up community water treatment systems that are designed to recover their costs and provide paid employment for local residents. Especially in peri-urban areas, the private sector has been playing an increasing role in providing water to low-income consumers; small-scale entrepreneurs pump, treat, deliver, and sell water that they obtain from public or private water sources.

The field trials explored all of these approaches and more in order to gain insight into potential markets for the SE200. Various field trial sites examined the marketing requirements, financing options, and viability of the following operating models:

- Community water committees: Not-for-profit community-operated systems can keep the cost of water treatment to a minimum, so that more households can benefit from the technology. Volunteers at a field trial site in Zimabawe, for example, treated water from neighborhood boreholes to supplement irregularly available municipal water. Their experience suggests that the volunteer model may be unsustainable without additional incentives and community support. The volunteers wanted uniforms to make them appear and feel more official, and they also suggested erecting a small kiosk where they could sell other health and hygiene products to subsidize their contribution to the community.

- Small retail kiosks: The SE200 has the potential to empower local entrepreneurs: they can create a viable business that generates income for themselves, while improving access to safe water in the surrounding community. In Kenya, for example, a micro-entrepreneur participating in the field trials used the SE200 as the primary treatment for water coming from her deep well. Her customer base has grown, and she is expanding the business with a submersible pump and 3,500-liter tank so that customers can fill containers more quickly.



Different operating models for the SE200 were tested at diverse field trial sites.

- Business franchises: Pureflow Water Solutions sells water treatment systems to businesses and middle- to upper-income households in Kenya. In a quest to reach lower-income consumers, Pureflow is piloting franchise water refill kiosks around Nairobi. These kiosks use the company's own high-quality multi-stage filtration and ultraviolet water treatment system to treat water before packaging and selling it in branded 20-liter containers. The kiosks use the SE200 to clean the containers before refilling them. This unique application reveals a secondary use for the SE200 beyond primary water treatment. This use may inform different iterations of the instruction manual and accessory kits to specifically address container cleaning.

- Schools and community centers: Water is not typically bought and sold at public institutions such as schools, health clinics, and community centers. By supplying safe, treated water to the people who patronize them, however, these institutions can directly contribute to the health of the community and also provide a role model for local residents. The small scale and low cost of the SE200 makes it a good solution for institutions that serve dozens or hundreds of people daily.

- Humanitarian assistance and disaster relief: Because the SE200 is portable and can be quickly and easily set up at any water source, it offers a potential solution to safe water needs in the aftermath of a natural disaster or other emergency. During a disaster simulation exercise in Thailand in July 2010, the United States and Thai militaries assessed the appropriateness of the SE200 as a tool for humanitarian assistance. The SE200 was determined to be an effective tool for Humanitarian Assistance and Disaster Relief missions, particularly for its low cost, portability, ease of use and low-maintenance requirements. Users were confident in their ability to operate and maintain the SE200 after a brief training.

Performance results and feedback on the technology

More than a dozen field trial sites returned constructive feedback on the SE200 over a six-month period. The devices distributed for the field tests remain in use in their various locations, and PATH continues to receive constructive, informal feedback from their operators.

To validate the treatment effectiveness and as part of PATH's monitoring and evaluation of the SE200, microbiological water quality tests were conducted at one site in Kenya. In the peri-urban community of Kasule, researchers collected and tested water samples from a variety of sources in both the wet and the dry seasons. These sources included three wells, one of which was operated by a micro-entrepreneur using the SE200, a municipal tap, a water cart vendor, a school, and 20 local households.

Operators requested clearer labeling on the device, for example, changing the labels for the indicator lights to read "low salt" instead of "salt" and "low battery" instead of "battery." They also suggested marking the start button with the word "start" or "on." Some operators recommended redesigning the start button to increase tactile feedback because they found it difficult to know whether they had pushed the button all the way. In addition, operators suggested placing a label on the SE200 that describes its use, for example, "This makes 60 ml of 0.75% chlorine solution."

The field trials highlighted a need for additional guidance on several key issues. The first is dosing. Operators wanted more detailed instructions on dosing, including optimal dosing options for different sized water tanks; that is to say, operators wanted more guidance on how many and what size water tanks would be optimal for their desired water volumes, so their customers would not have to wait in line. They also requested spoons to measure out the correct amount of chlorine solution to treat 5- and 10-liter containers, in addition to the spoon currently provided to dose 20-liter containers and the cup provided to dose 200-liter containers. Batteries, which were often mistreated in the field, pose another challenge. Overcharging and corroded contacts can reduce the life of a battery and affect safety. Operators require additional information on the appropriate size and type of battery and battery charger that can be used with the SE200.

Other issues emerged in specific settings. Turbid water needs to be filtered before it can be effectively treated with a chlorine solution. Operators faced with turbid water sources wanted a pre-filter to be supplied with the SE200 or, at the least, to be offered some guidance on pre-filter options. The car batteries that power the SE200 need to be periodically recharged. In rural settings with no access to mains power, operators requested a solar power option for recharging the battery.

Finally, the field trials revealed a demand for a larger-capacity electrochlorinator in certain situations. A larger-capacity device would be useful when there is a high throughput of clients or when a free distribution program leads to higher demand for safe drinking water. In such situations the batch size produced by the SE200 may be a limiting factor that extends wait

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The field trials in Zimbabwe identified unanticipated challenges to using the SE200, such as difficulty filling the device to a consistent volume when no flat surfaces were available.

times for consumers. In Tanzania, for example, Groundworks, a socially focused business enterprise that operates a kiosk selling treated water, estimated that it would take 3.5 hours daily to treat 5,000 liters of water with the SE200, excluding preparation time. They wanted a system that could produce enough chlorine solution to treat 5,000 liters of water in one hour or less.

Further investigation is needed into the number of clients served and the volume of water treated per day in different use scenarios and settings. Another question is how many device runs operators consider acceptable, given the labor required. While there are other electrochlorinators on the market that produce larger volumes of chlorine solution, they do not incorporate the smart technology that makes the SE200 so easy to use.

Feedback on the operating models

Investigation of potential business models and financial scenarios for scaling up the SE200 began even before the field trials. Using the value chain framework,[12] a consultant analyzed the market for the SE200 in Kenya, including the entire system supporting the technology from inception to use. The main findings were as follows:

- Products: Many water treatment technologies are available in Kenya at different price points; these include relatively inexpensive chlorine solutions.
- Financing: There is no proven financing model to pay for a water treatment device like the SE200. In theory, small business loans for this purpose should be available from microfinance institutions.
- Distribution and sales: In most areas, distribution does not pose a problem for chlorine products currently on the market, but packaging and distribution are major cost components. Existing community water treatment businesses currently operate at a small scale, with many nongovernmental organizations running just one to five kiosks.
- Communication and marketing: Marketing is mostly limited to education at the point of sale, although there is some use of community meetings and local radio advertising. With little traditional marketing being used to drive demand, there is an opportunity to test promotions and demand-generation techniques.
- Customer service: Minimal research has been conducted on consumer feedback, user experience, and market segmentation. User research could help inform different aspects of the value chain, including behavioral barriers and triggers and opinions of water treatment products.

Thus, important gaps and opportunities exist within the value chain, especially with regard to accessing credit to purchase water treatment products, scaling up water treatment businesses, using marketing and advertising to drive demand for safe water, and conducting user research.

While the value chain analysis focused on Kenya, experience from the field trials shows that some of these issues are also relevant in other countries. For example, there was limited uptake of water treated with the SE200 at most field trial sites, suggesting a need to stimulate awareness and demand through promotion. Implementing partners felt that the lack of marketing by kiosk operators was a contributing factor and that many community members were not aware of the benefits of safe water. Local operators of the SE200 recognized the problem and expressed interest in learning more about marketing and the use of promotional materials. They wanted guidance on how to sensitize the community to the need for treated water and effectively communicate the health benefits of water treated with the SE200.

Even in communities where an understanding of health benefits exists, challenges are still present. In one atypical site in Mutare, Zimbabwe, the community had an understanding of the need for treated water, community leaders supported the trial, and the amount of water treated daily increased fivefold over a three-month period. But it remains unclear whether people are willing to pay for treated water, as a community water committee managed the SE200 and distributed the water free to local residents. This is an unsustainable model in most settings.

In addition to field trials pointing to the importance of generating demand by raising awareness of the health benefits of safe drinking water, Mutare and other sites raised the importance of communicating with potential customers so they have trust and confidence in the SE200. A focus group participant in Mutare explained that, "[I] know it works as there have been no cases of illness (diarrhea or cholera) since the start of the SE200." This may call for some combination of educational activities and product advertising in conjunction with the launch of the SE200.

A field partner in Guinea shared some relevant experience with selling locally produced chlorine. Door-to-door sales proved more successful than selling chlorine at a retail kiosk. Community members preferred direct contact with the vendor, which created an opportunity for a longer conversation about the product and its benefits. Building on this model, a field partner in Kenya is planning to expand home delivery with either a small branded truck or a motorbike pulling a trailer.

Feedback from the field trials also demonstrates the importance of understanding the target market when introducing the SE200. In urban Tanzania, for example, Groundworks noted that an aversion to a strong chlorine taste and smell limited sales when containers cleaned with chlorine were not properly rinsed before filling. Pureflow received similar complaints in Kenya and resolved the problem by implementing a new process for rinsing containers. Pureflow, which is targeting a lower- to middle-income market segment, also had to fight the perception that their product was inferior in quality based on the look and feel of the storage containers and the sales kiosks. In response, they are renovating the kiosks and substituting dispenser-type bottles for the jerry cans originally used. In Zimbabwe, SE200 kiosk workers were given jackets with the message "Water is Life" to raise workers' status and give the perception of being part of an organized community water project.

"[I] know it works as there have been no cases of illness (diarrhea or cholera) since the start of the SE200."

Lessons learned and next steps

Repeated cycles of product testing enabled PATH and CDI to 1) identify challenges early in the development of the SE200, 2) address design problems before it goes into production, and 3) gain insights into potential markets for the device. The lessons learned will improve manufacturing, commercialization, and implementation.

With regards to manufacturing, CDI has moved from pre-production prototype fabrication to low-rate production. This will improve manufacturing efficiency, reduce costs, and allow CDI to keep up with increasing demand. The team is also researching supply chains to enable efficient distribution of SE200s to target markets. A better understanding of supply chains will also open communication channels between operators, distributors, and CDI to ensure technical support and market data can flow freely and efficiently.

With regard to ongoing product development, research findings on variable salt grain size and composition are being used to improve the design of the brine container and the accompanying directions in order to avert further operating problems. Additionally, PATH and CDI are exploring funding opportunities to design and test various product options and accessories to meet the needs of specific audiences, including:

- More robust and user-friendly dosing mechanisms for variable volumes.
- A pre-filter option for communities with turbid water sources.
- Solar-powered charging options for rural populations without access to electricity.
- A higher-capacity device for treatment of large tanks of stored or transported water.

One of the lessons learned from the field trials was the importance of matching the batch size of the SE200 to the size of commonly found water storage containers—which varies geographically—in order to minimize dosing challenges for operators. A family of smart electrochlorinators with different capacities may prove helpful in meeting the needs of different regions.

With regard to business operations, the field trials produced valuable information about generating demand for treated water, the market for the SE200, and the market context. Both water kiosk operators and customers showed initial signs of acceptance of the SE200, and the kiosk strategy showed promise in meeting the safe water needs of poor communities. Additional activities are being planned to finalize the commercialization of the SE200, aid in scaling up the device, and expand its use to more locations. For example, limited access to credit has long posed an obstacle to community water supply and treatment systems. Team members met with a micro-lending agency in Kenya to investigate potential solutions; the meeting identified a potential customer base and future lending opportunities.

Future plans include:

- Refining and improving training materials.
- Identifying best uses for the SE200 and engaging with potential purchasers.
- Exploring distribution channels and financial models to ensure sustainable, profit-based incentives at each point in the distribution chain.
- Developing and validating business models, including retail water kiosks.
- Creating micro-financing options to help entrepreneurs set up successful water businesses.
- Producing marketing tools and a business advice kit for entrepreneurs and community water committees.

Additional trials of the SE200 also are planned in several geographic regions to validate its use in scenarios where financial success is not the driving force. The goal will be to find sustainable operating models for institutions, such as schools and health clinics, and for humanitarian assistance and disaster relief efforts.

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