# BALANCING COMPETING PRIORITIES IN WATER FILTRATION: AN ANALYSIS FOR AMOS HEALTH AND HOPE

A Final Capstone Report for Master of Development Practice Candidacy

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# EXECUTIVE SUMMARY

AMOS Health and Hope, a non-governmental organization (NGO) located in Managua, Nicaragua, is working to bring safe water to communities across rural Nicaragua. For the past several years, they have distributed point-of-use (POU) water filters and conducted educational trainings relating to the filters as they implement filtration projects in communities. Though AMOS is aware of and presently piloting several different POU filters, they sought to better understand the literature around POU filters and other filter technologies available that could potentially meet their needs. To provide this, we conducted a cost and feasibility comparison of the filters identified for potential use.

We elected to compare the technologies AMOS is currently piloting (**ONIL and SAM III**) to thr.ee other technologies identified in our market research: a filter made in India and distributed in Nicaragua (**Safi**), one made locally in Managua (**Filtrón**), and one made in the United States that is also being field-tested in Nicaragua by a small Minnesota-based NGO[1] (**Sawyer**). A summary comparison of these five filters is illustrated in **Table 1**.

***Table 1: Summary of POU Filter Technologies Considered in this Analysis***

| Filter | Type | AMOS Use Status | Cost for Filter Part | Lifespan | Distributor |
|---|---|---|---|---|---|
| **ONIL** | Ceramic Candle | Piloted - In Use | $22.00 | 1 year | Nicaragua |
| **Safi** | Ceramic Candle | New - Not Used | $12.50 | 4 months | Nicaragua |
| **SAM III** | Hollow Fiber Membrane | Piloted - In Use | $60.00 | 10 years | United States |
| **Sawyer** | Hollow Fiber Membrane | New - Not Used | $60.00 | >20 years | United States |
| **Filtrón** | Ceramic Pot | New - Not Used | $28.75 | 1 year | Nicaragua |

[1] Compatible Technology International

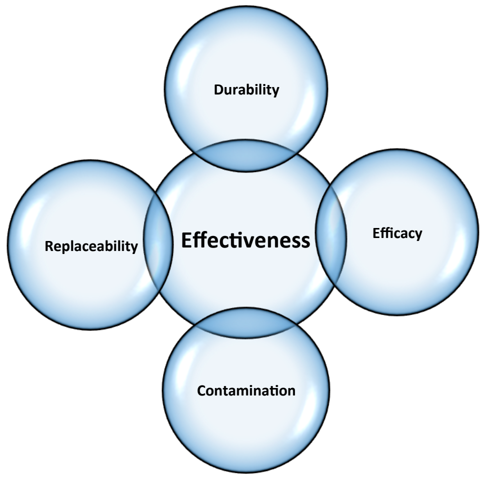


*Figure 1: Factors of Filter Effectiveness*

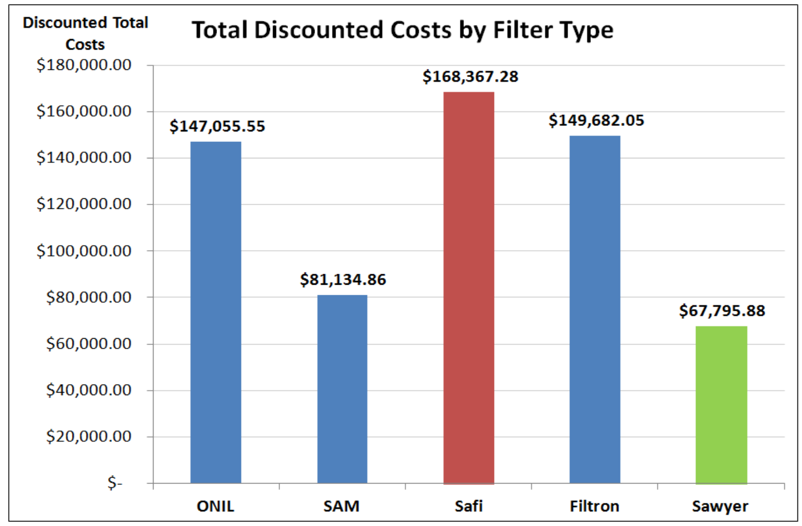


*Figure 2: Total Discounted Costs by Filter Type*

After selecting filters to include in the assessment, we conducted a financial analysis to compare overall costs of implementing a water filtration project using each of the five filters. **Figure 1** illustrates the differences in total discounted costs for all filters, showing that the Sawyer filter is the most cost-effective of the five considered. A sensitivity analysis was also conducted to determine which fluctuations in project implementation (transportation costs, filter costs, breakage rates) had the greatest effect on the project's financial viability. Transport costs and variance in filter breakage rates (rates for "in use" only) were found to be the two biggest drivers of project cost. **Thus, unanticipated changes in fuel prices or an unexpected number of trips to the community would significantly increase program expenditures and should be accounted for in program planning.** Similarly, choosing durable filters and/or including user training to prevent breakage could have substantial financial payoff.

Financial costs associated with each filter are only one aspect of an effective program. A feasibility analysis was conducted to examine the many non-monetary factors that drive filter usage and prevention of disease. We examined the filters across eight characteristics: **Efficacy, Ease of Use, Flow Rate, Likelihood of Recontamination, Durability, Portability, Replaceability, and Potential for Business.** Ultimately, cost alone cannot guide filter choice - two other factors determine long-term usage:

First, **can the filter realistically be used in a home in a way that will effectively prevent disease? Figure 2** illustrates the key characteristics that help determine effectiveness.

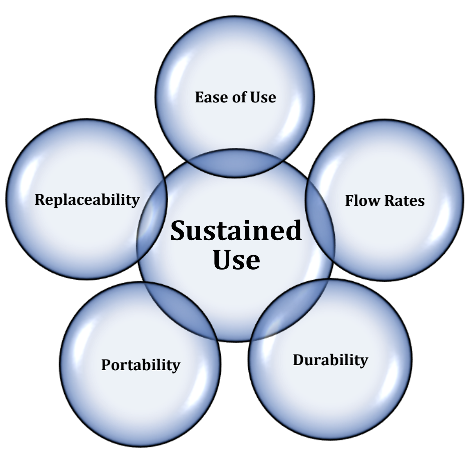


*Figure 3: Probability of Sustained Use*

Second, **is the filter easy enough to use that households will continue using it? Figure 3** illustrates the key factors that determine probability of sustained use.

Ultimately we chose to evaluate the five filters based on four main value models: the filter's **availability** (can it be attained locally?), **transition to community management** (is there any potential for an eventual market model so AMOS is not the middle man?), **ease of use** (is filtering water simple enough that families who want to use the filter will continue to do so?), and **affordability** (of not only the filter itself, but also of any additional maintenance or replacements).

Based on our cost comparison, sensitivity analysis, and feasibility analysis, as well as our understanding of the context in which AMOS is working, we have identified four different value models for determining which filter to recommend.

1) If **Local Availability** is highly valued: **ONIL**
2) If **Ability to Transition to Community Filter Management** is highly valued: **ONIL**
3) If **Ease of Use** is highly valued: **SAM III**
4) If **Affordability** is highly valued: **Sawyer**

Outside of these analyses we identified other factors likely to influence program planning and priorities including measuring diarrhea rates in homes with filters versus those without to more clearly demonstrate the impact of water filtration on health, accounting for variance in transport costs and filter breakage in filter choice, and proposing a market model based on a voucher system that will help to establish a supply chain in the community and create a system of service-provider accountability to filter users. In conclusion, based on our analysis and the organizational goals and priorities of AMOS, ONIL and SAM III are excellent technologies to pilot in rural Nicaragua. If financial cost and long life-span of a filter product are high-priority attributes, the Sawyer filter may be another product to consider.

# INTRODUCTION

Availability of safe water can save lives. The centralization of water treatment systems is one of the main strategies for the provision of safe water to populations. Centralized water treatment systems are expensive and complex to develop, especially for rural areas with low population density. Point-of-use (POU) water filters increase access to safe water, typically at the household level. However, many water filtration programs have met with significant challenges in maintaining filter use due to breakage, supply chain issues, usability, cost of maintenance and replacement, and many other factors. Due to challenges in sustaining use of existing filter technologies, AMOS Health & Hope has begun to explore other filtration options.

In the past, AMOS piloted Biosand filters[2] and Tulip filters[3] in communities. Over the course of about a year, AMOS noticed that the biosand filters would be damaged during attempted transport to another location and Tulip filters were especially easy to break during maintenance routines. As such, AMOS decided to pilot two new technologies: ONIL and SAM III. These newest POU filter technologies have been in communities for as little as two months and as long as six months. While AMOS is in the refining stages of its pilot filter project, the organization asked us to conduct a more in-depth analysis of filters that could potentially meet their needs and the needs of the communities in which they work.

In this analysis, we will review available technologies for point-of-use water filtration, describe our information gathering techniques, present the data from our cost-comparison analysis and discuss its implications, provide a discussion on the feasibility of use and the likelihood of continued use, explore options for a market-based model for filter distribution, and provide recommendations for future programming.

# BACKGROUND RESEARCH

To gain a better understanding of existing technologies and innovations in water filtration, we first conducted a literature review of rural point-of-use (POU) water filtration technologies, sustainability of water filtration programs, theories of behavior change, and an exploration of filter options that AMOS has not previously used. This report draws upon that work[4].

We used the literature review to improve our understanding of the advantages and disadvantages of several filter technology types currently on the market – biosand, ceramic, and nutshells – and the use of nanoparticle treatments to increase filter efficacy. We compared the benefits and drawbacks of these thr.ee filter technology types (**Table 2**).

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[2] A biosand filter (BSF) is "a household scale, intermittently operated slow sand filter" (Stauber, Elliott, Koksal, Ortiz, DiGiano and Sobsey, 2006). As water passes through the BSF's layers of sand and gravel, particulate matter is removed. A living layer of beneficial bacteria living in the filter substrate also remove disease-causing microbes from the water.

[3] A Tulip filter is a silver-impregnated ceramic candle type filter which uses gravity siphon pressure to force water through the filter (Tulip Water Filter, 2010).

[4] The completed Literature Review has already been provided to AMOS Health and Hope.

*Table 2: Comparison of Filter Technologies Identified During Literature Review Stage*

Benefits and Drawbacks

| Type of Filter | Benefits | Drawbacks |
|---|---|---|
| **Ceramic** | One-time cost (little maintenance) | Tendency to clog if water is turbid; requires regular cleaning |
| | Proven effective at removing disease-causing organisms | Low flow rate, especially when clogged |
| | Potentially locally produced – more environmentally sustainable | Not as effective against smaller viruses |
| | | Effectiveness tends to decrease over time (~3 year lifespan) |
| **Biosand** | Faster flow rate | High potential for recontamination |
| | Average 93% reduction in bacterial load | Requires several weeks to develop bio-level and attain optimal efficiency |
| | High availability and low cost of materials (PVC, cement, sand, gravel) | Heavy and very difficult to move between residences or within the home |
| **Nutshell** | Inexpensive! | Not designed for household/POU |
| | Organic material readily available | Not readily available |
| | Less adsorbent required than commercial filters | |

In comparing ceramic, Biosand, and nutshell filters against one another, the largest trade-offs include cost, ease of use, accessibility and filter efficacy. Ceramic filters are easily accessible and highly effective, but they have issues in their propensity to clog, low flow rates, and declining efficacy over time. Biosand filters are both cost effective and effective at bacterial load reduction, but they have ease of use concerns as well, with high potential for recontamination, and a several week "maturation" period to become ready to use. Nutshell filters are also inexpensive, but have tradeoffs in local availability and efficacy of bacteria removal. Additionally, nutshell filters have not yet been used on a large scale.

To further explore potential filter options for AMOS within these thr.ee types, we researched specific filter brands and models that are emerging or that may not have been explicitly discussed in the literature. Resulting from this initial review, we compiled **Appendix A**, which demonstrates the pros and cons of each filter brand and / or type. Filters considered in this stage of the research included:

- **Potters for Peace - Filtrón:** A ceramic pot-type filter manufactured in Nicaragua
- **Hydraid**: A biosand filter with housing and substrate supplied by a US manufacturer
- **ProCleanse**: A single unit water filtration and storage system using porous ceramic particles and positively charged ions, manufactured in the US
- **Nutshell**: Activated nutshell carbons filter non-organic matter from water; not suited for bacterial load reduction

We narrowed our examination based on conversations with AMOS staff and a better understanding of the filter attributes they deem important, namely affordability, scalability, and portability. As such, the following filters were eliminated from our analysis list: ProCleanse (due to prohibitive cost), nutshell filters (due to lack of scalability), and Hydraid (and other slow sand filters – due to concerns of portability). For a more in-depth description of the ProCleanse and Hydraid filters, see **Appendix C**.

Ultimately we compared the two filter technologies currently in pilot phase – ONIL and SAM III – with the Filtrón (Potters for Peace) filter. As will be discussed in the Field Research section, we added two more technologies at that stage of the project – Safi and Sawyer filters[5]. All five filters (**Table 3**) will be discussed in more detail in the Filter Description section of this report.

***Table 3: Summary of POU Filter Technologies Considered for this Analysis***

| Filter | Type | AMOS Use Status | Cost for Filter Part | Lifespan | Distributor |
|---|---|---|---|---|---|
| **ONIL** | Ceramic Candle | Piloted - In Use | $22.00 | 1 year | Nicaragua |
| **Safi** | Ceramic Candle | New - Not Used | $12.50 | 4 months | Nicaragua |
| **SAM III** | Hollow Fiber Membrane | Piloted - In Use | $60.00 | 10 years | United States |
| **Sawyer** | Hollow Fiber Membrane | New - Not Used | $60.00 | >20 years | United States |
| **Filtrón** | Ceramic Pot | New - Not Used | $28.75 | 1 year | Nicaragua |

*Note 1: also Table 1 in Executive Summary*

# FIELD RESEARCH

Through the literature review process, thr.ee main gaps in our understanding became apparent. First, we needed to understand the user experience of how filtration technologies integrated into household and village life, and to better understand how product attributes impact user satisfaction. Second, we needed a more in-depth understanding how AMOS implements their filter programming in order to provide a thorough and realistic analysis. Lastly, we encountered a scarcity of information regarding other filter technologies available in Nicaragua.

In order to address these thr.ee gaps in our understanding, members of our team traveled to Nicaragua from March 13-23, 2014. During the visit we:

1) **Visited Cumaica Norte, a village currently using Biosand filters;**
2) **Met with Lester Orente, the water filtration program coordinator;**
3) **Met with Luis Marchena, a local distributor of Safi filters.**

In Cumaica Norte, we interviewed four families and the community health promoter about their filter use and the local water systems. Many families have water piped to their home; water faucets are usually located outside the home. Families who do not have direct access to water are often able to obtain their water from a neighbor's faucet. Water comes from a gravity-based centralized water system, with the main tank located about thirty minutes from the community and fed by spring water.

[5] The team became aware of the Sawyer and Safi technologies while conducting field research in Nicaragua, so these filters were late additions to the analysis.

The tank and pipes are regularly treated with chlorine by a técnico hired by members of the community's water committee.

Of the four families we interviewed, those who had stopped using their filters did so primarily because the filter had broken. One broke while trying to move the filter. The other household was not sure how theirs had broken, but the woman with whom we spoke believes a friend tried to move it but did not put it back correctly. Prior to breakage, she also felt the filter was difficult to maintain because it required filling twice daily every day. Those who had broken filters did not have a clear idea of how to get their filter repaired or replaced. Of those who have continued to use the filter, one individual reported that she had no complaints about the filter. When she leaves town she has someone fill the filter for her. The other individual would prefer that the filter were more mobile, as she would like to move the filter to a different location.

During our time in AMOS headquarters, AMOS's Water Filtration Program Coordinator (Lester Orente) described their behavior change programming, water filtration technologies currently being piloted (SAM III and ONIL), preferred characteristics of filter technologies, and upcoming organizational plans. He emphasized the importance of efficacy, effectiveness at removing turbidity, portability, and local availability for future AMOS use of filter technology. One challenge Mr. Orente faces in implementing projects is that the health promoters, who are currently in charge of the project, have many demands on their time. As a result, they are often unable to provide adequate filter monitoring and supervision to all households with filters; instead, households in the immediate vicinity of the health promoter base or home receive the most attention. He is proposing a water promoter position to focus directly on water filtration and water quality for future filter programming.

While in Nicaragua we also learned of another filter technology, Safi, which could possibly meet AMOS's needs. During our meeting with the local distributer, Luis Marchena, we were able to see both the Safi filter, as well as an arsenic filter, which they are currently developing. It was useful to see these two technologies in person and to interact with the filter components. We present the advantages and disadvantages of the Safi filter in greater detail in the next sections.

This field research played a crucial role in addressing our gaps in knowledge. During our visit we gained an improved understanding of the role of delegations[6] in AMOS programming - depending on the situation and need, delegations may transport filters to Nicaragua from the U.S. (this is historically true of SAM III filters); they may also facilitate education and training workshops, participate in filter installation, or contribute to monitoring and supervision activities. Our engagement with AMOS staff was crucial to highlighting the importance of portability, reliable supply chains, and the benefits of local production or suppliers for future filter programming. Lastly, we were able to present our findings to AMOS staff to seek input and insights that could guide our analysis. Ultimately, the information gathered during our visit greatly impacted the development of the cost-effectiveness analysis, feasibility analysis, and resulting recommendations.

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[6] Delegations are groups of individuals from the U.S. who arrive in Nicaragua for a period of 1-2 weeks, approximately, to perform work on various AMOS projects, including the filter project.

# FILTER DESCRIPTIONS

In our analysis, we assess five different water filtration technologies, two of which are already being piloted by AMOS **(Table 4)**. The other thr.ee filters listed could potentially meet AMOS's needs, as outlined in the Field Research section, and are therefore included in this report's comparison.

***Table 4: Filter Technologies Considered for this Analysis***

| Filter | Type | AMOS Use Status | Cost for Filter Part | Lifespan | Distributor |
|---|---|---|---|---|---|
| **ONIL** | Ceramic Candle | Piloted - In Use | $22.00 | 1 year | Nicaragua |
| **Safi** | Ceramic Candle | New - Not Used | $12.50 | 4 months | Nicaragua |
| **SAM III** | Hollow Fiber Membrane | Piloted - In Use | $60.00 | 10 years | United States |
| **Sawyer** | Hollow Fiber Membrane | New - Not Used | $60.00 | >20 years | United States |
| **Filtrón** | Ceramic Pot | New - Not Used | $28.75 | 1 year | Nicaragua |

As described in **Table 4,** two of the filters (ONIL and Safi) are ceramic candle type filters and two (SAM III and Sawyer) are hollow fiber membrane type filters. The ONIL, Safi and Filtrón filters have distributors in Nicaragua, while the SAM III and Sawyer come from the U.S. Compatible Technology, Inc., a small organization in Minnesota that is field-testing the devices in Nicaragua, is piloting the Sawyer filter. Potters for Peace, another NGO in Nicaragua, manufactures the Filtrón filter locally. All of the filters have been shown to effectively remove bacteria and parasites and decrease turbidity. All filters make use of buckets (either one or two), which can be purchased in country[7].

## ONIL

The ONIL filter is a silver-impregnated ceramic filter[8] that fits into a two-bucket system **(Figures 4 and 5).** It lasts for about one year, and costs $48 for the filter mechanism and bucket system **(Figure 5)** or $22 for the filter mechanism alone. The filter must be scrubbed clean to allow for adequate filtration rates, but scrubbing does reduce filter size over time. However, the filter never needs to be sterilized or boiled. There is a distributor of ONIL filters in Nicaragua.

[7] Whether or not these buckets are BPA-free is not clear. None of the technical literature addresses this and it was not discussed with market vendors if buckets are purchased in country.

[8] Ceramic filters can be treated with silver nanoparticles to increase the efficacy of filtration (Savage and Diallo, 2005).


*Figure 4: ONIL Filter Housing*

*Figure 5: ONIL in Clear Bucket System with Close-Up of ONIL Filter Mechanism*

## SAFI

Similar to the ONIL filter, the Safi filter is also a silver-impregnated ceramic filter. It is smaller in diameter than the ONIL filter, so it must be replaced more frequently, thr.ee times a year. The filter mechanism, as seen in **Figure 7,** costs $12.50. It comes with a scrubbing sponge, cloth cover for improved functioning in turbidity, and a measuring device to determine when to replace the filter **(Figure 7).** There is a distributor in Managua, and he plans to sell the filter with a two clear bucket system **(Figure 6)**.

*Figure 6: Safi Filter Clear Bucket Housing*

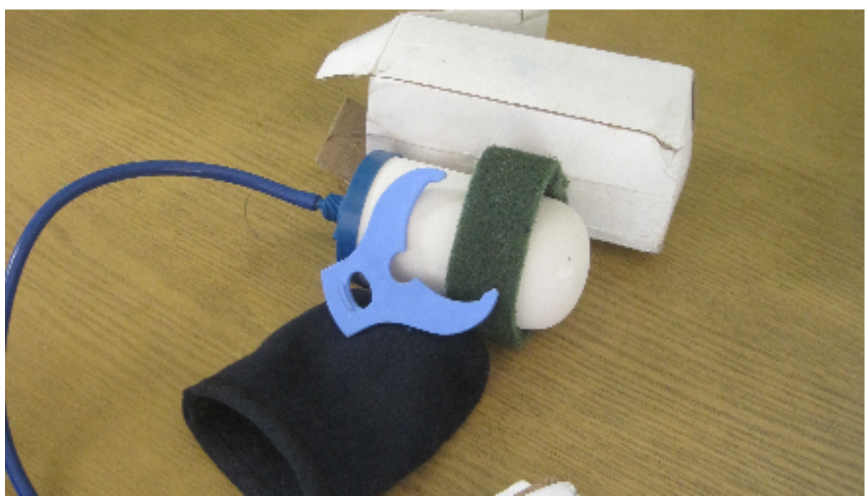

*Figure 7: Safi Filter Mechanism, Tubing, Cloth Sleeve, and Measuring Device*

## SAM III

The SAM III filter is a hollow fiber membrane filter. It is contained within one bucket, which has a spigot **(Figures 8 and 9)**. Other forms of this filter use a modified slow sand filter, followed by membrane filtration, in a single step process. Based on our conversations with Mr. Orente, AMOS plans to use the single step process. The filter costs $60 and comes with a syringe for back flushing to maintain the filter. SAM III's anticipated lifespan is 10 years. At this time, there are no distributors in Nicaragua, so parts must be shipped from the United States.


*Figure 8: One-Bucket System of SAM III Filter in Use in Rwanda*

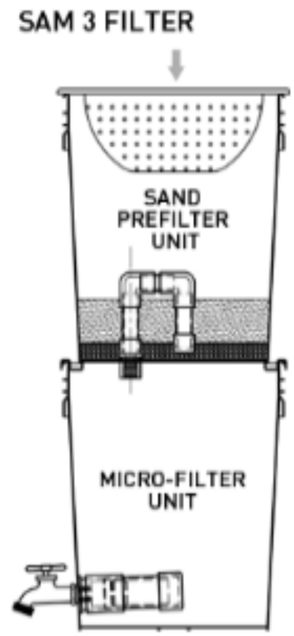


*Figure 9: Two-Bucket System with Sand Filter and Hollow Membrane Filter*

*Figure 10: Sawyer Filter in Use in Two-Bucket System*

### SAWYER

Similar to the SAM III filter, the Sawyer filter is a hollow fiber membrane filter. It is typically set up in a 2-3 bucket system, with the filter outside of the bucket and tubing connecting the bucket to filter to bucket **(Figure 10)**. The tubing is attached to the filter mechanism. The entire filter system costs $60. Hollow fiber membrane filters utilize membranes to trap chemicals and bacteria, taking advantage of differing concentrations of particulate matter and hydrostatic pressure to filter the water. Filter mechanisms must be shipped from the U.S., but there are other organizations using Sawyer filters in Nicaragua with whom AMOS may be able to partner or exchange filter parts.

### FILTRÓN

The Filtrón filter, made by Potters for Peace, is a ceramic pot filter (larger than the ONIL and Safi filters), with impregnated silver. These filters are made in

*Figure 11: Filtrón Diagram and Filter with Bucket System.*

Nicaragua. The ceramic filter is placed in a bucket with a spigot (**Figure 11**). The whole system costs $28.

# FINANCIAL ANALYSIS

After determining which filtration technologies warranted further evaluation, we conducted a financial analysis to determine the filter project's financial implications for AMOS. Our goal was to provide AMOS with information regarding the financial costs they (and they communities in which they work) would bear for various aspects of the filter programming. The main costs anticipated and examined include:

1) **Operational costs** (programmatic and administrative fees that are the same across filters, as well as costs incurred from breakage that differ across filters)
2) **Costs for SAM III and ONIL filters** (maintenance and replacement costs of the filters that are currently piloted by AMOS)
3) **Costs for Safi, Filtrón, and Sawyer filters** (maintenance and replacement costs of the filters that could potentially be piloted in the future)

The costs for filters (those currently being piloted and potential future options) included the costs of brand new filters as well as the costs incurred at intervals in which households are expected to replace the various filter components (or the entire device). The remainder of this section further details our methodology, the assumptions we made in estimating costs, as well as an analysis of the potential scenarios and how altering one assumption might affect the ultimate estimation of the costs.

## METHODS

**Cost Comparison Analysis**

The financial implications of the filter project were examined through a cost comparison analysis. This approach differs from a more traditional cost-benefit analysis in that it assumes static benefits across each of the filter types considered and instead compares the differences in cost between them. In using this analysis type, we assume that the filter benefits–namely, efficacy of the filters (bacterial load reduction) and their ease of use–are the same across each type. Assumptions for equal filter efficacy are based on sources reviewed in the literature and in **Appendix B**, which cite a bacterial load reduction of > 99% for all filter types. Our assumptions for each filter's ease of use state that the filters are comparable in terms of maintenance and daily operation; this assumption is examined more closely in our feasibility analysis. Because the benefits were assumed to be the same across filters, it was necessary only to consider the costs associated with each filter and how those costs differ between filters. The comparison is based on differing attributes of each filter type, such as filter lifetimes, breakage rates, replacement rates and associated costs.

**Scenario for the Analysis**

We based the analysis on a single filter program scenario where AMOS is expanding the filter project into a new community. This community and the filter introduction process are comparable to other communities they have worked in the past: the community is relatively remotely located with about 200 households. There are local stores where community members can buy basic food supplies and other necessities, but access to a larger commercial center involves a number of transit hours by car or by bus.

AMOS introduces filters to the community 45 at a time, and is in charge of all education, installation, and monitoring and supervision surrounding filter introduction. Whenever possible, AMOS makes use of delegations to both generate capital and as labor. While this is a major financial asset and component of AMOS's programming, our financial analysis does not distinguish between AMOS funds and funds brought to the project by delegations for cost line items because AMOS's working capital is generated through a variety of sources, and because delegation contributions may vary substantially from year to year.

The households that are receiving filters must attend thr.ee educational classes on sanitation, hygiene, and filter maintenance prior to filter delivery. AMOS delivers these courses as part of the installation process and behavior change model. Additionally, each household must pay a $20 "buy-in" for the filter. AMOS's involvement in filter support lasts for 20 years.

After the initial year, our model assumes that AMOS introduces 45 new filters every two years[9] until a "saturation point" of adoption is reached. At this point, we assume that there are no additional families in the community who lack filters but still desire them.

This "saturation point" will vary between communities, and it will directly affect the results of any financial analysis, so we considered costs based on thr.ee different scenarios (**Figure 12**). The first is a base model in which the community reaches saturation at 80% (160 of 200 households) adoption. The second is a low adoption rate scenario where the community reaches saturation at 60% (120 of 200 households), and the third involves a high adoption rate scenario in which 100% of families are assumed to adopt filters (this is AMOS's goal for every community).

[9] These filters are introduced in one shot (during the same time frame for all 45 filters) in an installation year.

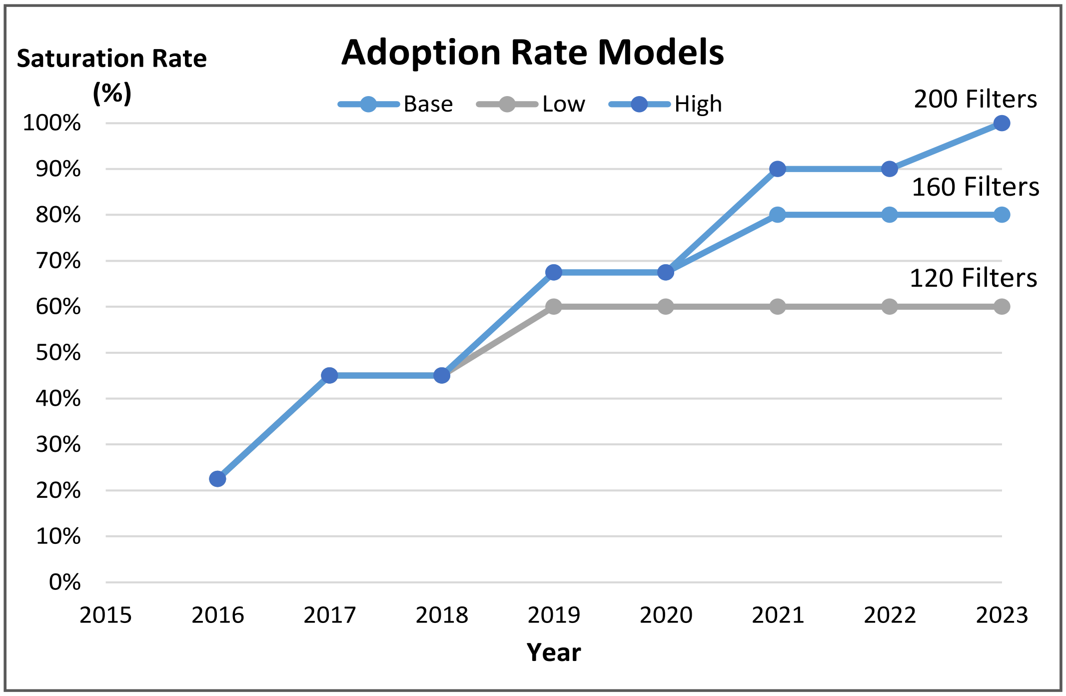


*Figure 12: Thr.ee Adoption Rate Models: Base, Low, and High*

**Creating a Basis of Comparison**

Discounted costs were calculated across the lifetime of the project for each type of filter in order to provide some point of comparison. These calculations take into consideration the discount rate (the fact that the value of money decreases over time). The Net Present Value (NPV) of discounted costs yields the value (in today's terms) of all the money that will be spent by AMOS throughout the duration of the filter project in the hypothetical community.

**Assumptions**

Five major assumptions were made for the purposes of the financial analysis:

1) An average AMOS community consists of 200 households.

2) AMOS will cover the majority of the costs incurred by filter installation (including initial filter costs, costs of transport, costs of breakage during transport, costs of installation of filters), while individual communities bear the costs of maintaining the filters (such as paying for replacement parts, costs of filter breakage during use).

3) AMOS does not have the capacity to bring the total number of filters desired by a community in one trip. Filters are introduced to recipient communities 45 at a time, in alternating years until the saturation point is reached.

4) A discount rate of 5% is acceptable for use in this project. This is based on an economic sustainability analysis of ceramic filters conducted by Ren, Colosi, and Smith (2013).

5) Breakage rates (as a result of both transport and daily use) are assumed to be 5% (an estimate provided by AMOS), unless further literature review suggested otherwise (for example, the

Filtrón by Potters for Peace is a silver-impregnated ceramic filter, which makes the ceramic more porous and therefore will have a higher breakage rate). If a different breakage rate was used, this was noted in the assumptions portion of the spreadsheet.

## Discussion of Results

### Cost Comparison

The results of the cost-comparison analysis show that the largest determinants of a filter's cost efficacy are the lifetime of its filtration mechanism and the cost of replacement of that mechanism. In the analysis carried out, the introduction of various filters in a filter project expansion scenario, the SAM III and Sawyer water filtration systems prove most cost effective. These two filters, despite their relatively higher initial cost, are more effective over the lifetime of the project due to their low replacement rates. An initially cheap filter like the Safi becomes less cost-effective over time due to its short lifetime; this also holds true for the Filtrón and ONIL filters. **Table 5** exemplifies some of these important differences between filters.

*Table 5: Variations in Determinant of Final Cost*

| | Initial Cost | | Lifetime of Filter Mechanism | Cost to Replace Filter Mechanism | |
|---|---|---|---|---|---|
| **ONIL** | $ | 38.20 | 1 year | $ | 22.00 |
| **SAM III** | $ | 60.00 | 10 years | $ | 12.50 |
| **Safi** | $ | 22.00 | 4 months | $ | 60.00 |
| **Filtrón** | $ | 28.75 | 1 year | $ | 60.00 |
| **Sawyer** | $ | 60.00 | 20 years | $ | 28.75 |

As **Figure 13** illustrates, the Sawyer filter has the lowest discounted costs over the lifetime of the project, at roughly $68,000. This is likely due to the fact that the lifetime of the Sawyer filter is estimated at 20 years. For the purposes of this project, this means there are no costs incurred for replacement of parts for the Sawyer filter, which helps keep the total costs low. The next most cost effective filter, the SAM III, has total discounted costs of around $81,000, which are still 20% higher than the Sawyer's costs. The ONIL and Filtrón filters have roughly comparable total costs in the upper $140,000 range, while the Safi filter has the highest total discounted costs at nearly $169,000, due to its high replacement rate.

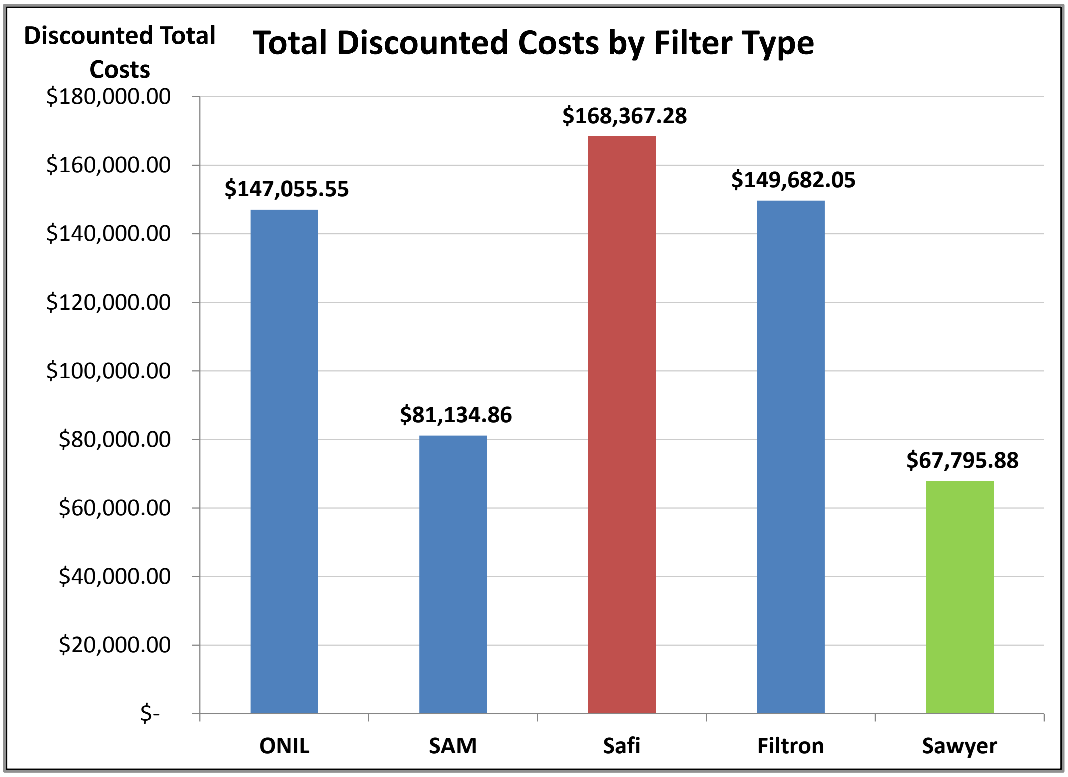


***Figure 13: Total Discounted Costs by Filter Type***

*Note 2: Same as Figure 1 in Executive Summary*

**Sensitivity Analysis**

After determining estimated costs for each filter including the replacement of parts at various intervals, sensitivity analyses were run to more closely examine how variations in components of the total cost affect the overall total costs of the filters. In conducting the cost comparison analysis, certain estimations were made about the rates at which filters would break, both in transit out to the communities and in everyday use. If these rates of breakage were to increase, project costs would also increase, as more money would have to be spent to replace filters more often. The inverse would be true if breakage rates were to fall. Conducting the sensitivity analysis allows AMOS to evaluate costs in what they believe to be the most accurate operating conditions. **Figure 14** below illustrates exactly how fluctuations in breakage rate, averaged across filters, affect total project costs.

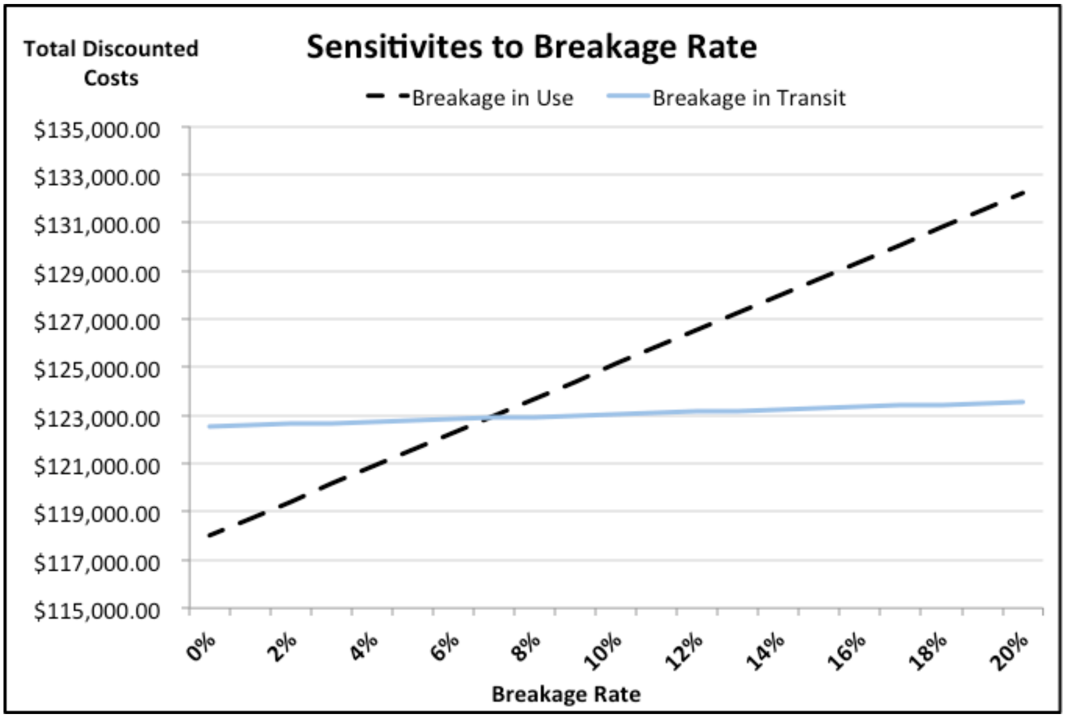


*Figure 14: Cost Sensitivities to Fluctuating Breakage Rates*

The slope of the lines in **Figure 14** indicate which breakage rate the project is more sensitive to, i.e., the breakage rate that has a larger effect on total project costs. Compared to fluctuating breakage rates in transit, breakage rates in use are much more important to the project's financial viability. By varying transit breakage rates from 0% to 20%, the project's average total costs change by roughly $1,000. Fluctuations in breakage from use over the same range change total project costs by nearly $14,000. Hence, the importance of low breakage during use becomes evident, and suggests that investment in educating filter recipients on proper filter handling and maintenance will yield financial gains.

Sensitivity analysis was also conducted to determine the effect of fluctuations in cost factors of transport and the initial costs of filters. A cost factor is a multiplier by which a price is multiplied to move that price up and down; for example, if the initial price of a filter is $60, and it is multiplied by cost factors of .75 and 1.25, the filter is also analyzed as if it cost $45 and $75. Filter and transportation costs were evaluated from 50% to 150% of anticipated costs. For filters, the change in total project costs over this range is $6,000. On the other hand, the difference over a similar range of transportation costs is $25,000. **Figure 15** illustrates the project's sensitivities to changes in transport and initial filter cost factors; it illustrates that transport costs have a much higher effect on total project costs, suggesting that AMOS should take precautions to maximize the efficiency of each time they transport filters to the field.

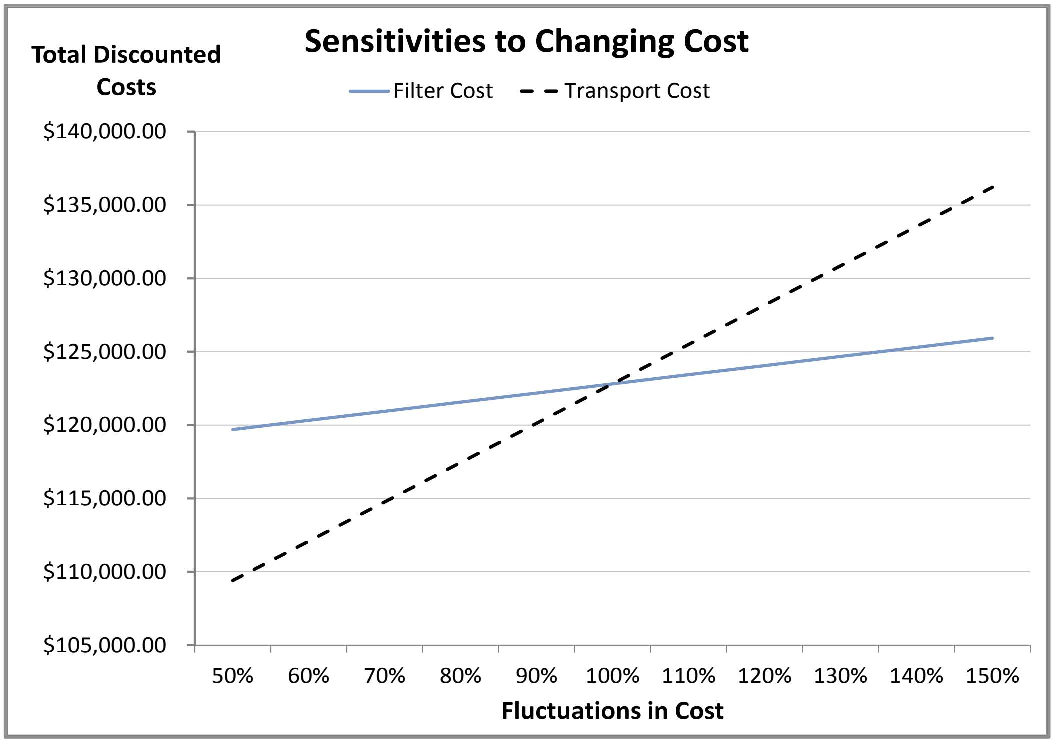


*Figure 15: Cost Sensitivities to Fluctuating Transport and Filter Cost Rates*

**Adoption Rate Scenarios**

Another question investigated in the PPA was how different levels of filter adoption would affect the financial analysis. We tested thr.ee different scenarios of adoption rate, in which 60%, 80% and 100% of households in a community acquire and use filters supplied by AMOS. **Figure 16** below illustrates these different total project costs. As is to be expected, a scenario in which 100% households are using filters is the most expensive scenario to AMOS. Nonetheless, 100% filter adoption is a worthy goal, as it essentially ensures complete protection of a community from water-borne disease and illness. It is important to note that although filter costs increase linearly to reach the last 20% of community members, programming costs such as education and outreach will likely need to increase substantially more to reach the last 20% of community members. Those last households who resist adopting filters will probably require additional investment in the form of staff time and programming in order to convince them of the benefits of using a water filter. This is an investment that should be considered but is not quantified here.

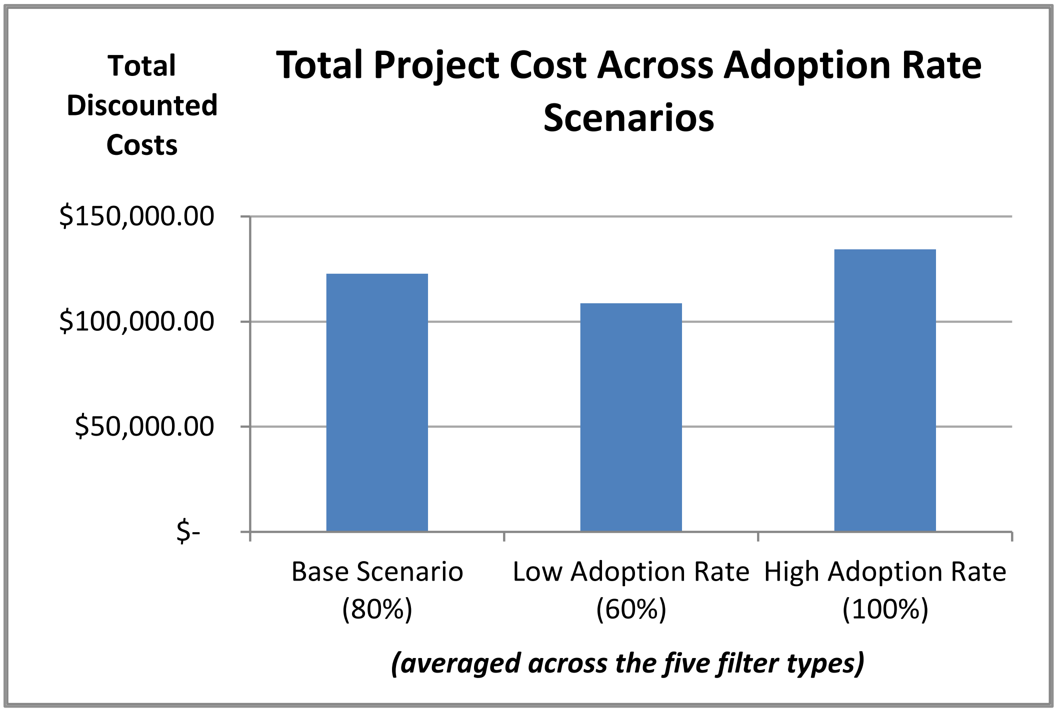


*Figure 16: Comparisons in Total Project Cost across Adoption Rate Scenarios*

**Recommendations**

***From the cost comparison analysis*:** Judging solely on the basis of cost-efficacy, the Sawyer filter is the most attractive option for AMOS's expansion plan. The Sawyer's high initial cost is offset by its lifespan of over 20 years, making it a financially attractive option for use in expansion of the filter program. The SAM III filter, the next cheapest filter of the five examined, is still 20% higher than the cost of investing in the Sawyer.

***From the breakage rate sensitivity analysis:*** Discounted costs are more sensitive to breakage in use than breakage in transport because breakage in use happens continuously. On the other hand, breakage in transport can only happen every time filters are transported. Investment in programming that teaches filter users about proper maintenance and handling of their filters, in an effort to reduce the breakage rate of filters in use will reduce costs in the long-term.

***From the cost factor sensitivity analysis*:** Discounted costs are more sensitive to changes in costs of transport than to changes in costs of filters, due to the fact that transport costs constitute a larger proportion of the project costs than filter costs. Unanticipated changes in fuel prices or the number of trips to the community would significantly increase program expenditures and should be accounted for in program planning. Because of the large proportion of total program expenditures dedicated to transportation, filters that require less frequent replacement and repair become even less expensive than based simply more frequent filter purchases alone. Efforts to perform multi-purpose trips to the community and transition to community management and maintenance of filters would provide substantial cost savings.

***From the adoption rate scenarios analysis*****:** A 100% rate of adoption of filters in a community is understandably the most expensive scenario for AMOS to support, but has important public health benefits. It is important to keep in mind that reaching 100% adoption of filters will be more difficult as the community's adoption rates increase. It will take a greater investment of staff time and programming to convince the last few households to adopt and use water filters.

# FEASIBILITY COMPARISON

Though cost is an important factor to consider in any program design, other key factors significantly impact program success. In order for the program to have meaningful impact, **participants must both be able to and choose to continue using their filters.**

We compared the five selected filters in eight categories:

- **Efficacy:** How well does the filter prevent disease?
- **Ease of Use:** How many steps are required to get water to the filter? How easy is the filter to maintain?
- **Filter Flow Rates:** How quickly does the technology filter water?
- **Likelihood of Contamination:** How easily can filtered water become re-contaminated?
- **Durability:** What is the average break time and lifespan of filters?
- **Portability:** How easily can the filter be moved from one location to another?
- **Replaceability:** How easily can the filter and its various parts be replaced?
- **Potential for Business Opportunity:** How well do the filter and its supply chain lend itself to a local business model?

## EFFICACY: HOW WELL DOES THE FILTER PREVENT DISEASE?

The most important quality in selecting a filter is that it effectively removes disease-causing agents. All five filters successfully filter at least 99.99% (**Table 6**) of coliform bacteria out of water (Helps International, 2014; Aqua Clara International, 2014; Wubbels, Duran, & Willems, 2008; IDEASS Nicaragua, n.d.; Sawyer International, 2014). **It is important to note that none of the filter technologies reliably reduce virus particles.** SAM III filters out 99.999% (Aqua Clara International, 2014) and Sawyer filters out 99.99999% of bacteria (Sawyer International, 2014). Practically speaking, these differences are unlikely to result in substantial differences in disease rates (WHO, 2011). It is also important to note that all rates listed in **Table 6** below are based exclusively on lab testing.

*Table 6: Efficacy Comparison Across All Filters**

Bacteria Removal Only (No Virus Particle Removal)

| | ONIL | SAM III | Safi | Filtrón | Sawyer |
|---|---|---|---|---|---|
| Efficacy | 99.99000% | 99.99900% | 99.99000% | 99.99000%** | 99.99999% |

** All rates listed above are based on lab testing.*

*** Rate reduced to 90% after 4 years of use.*

Unfortunately, at present, there is limited data on real world and prolonged use. In a study by Bielefeldt, Kowalski, and Summers (2009), Filtrón filters were only able to remove 90% of bacteria after four years of use. A 90% filtration rate fails to meet WHO criteria as protective household water treatment (WHO, 2011). Similarly, Hwang (2003) found that 80% of households had less than 2.2 colony forming units (CFUs)/100 mL (bacteria that grow out on culture plates) of water during six months of monitoring PFP filters. This also does not meet the WHO guidelines for drinking water of 0 CFUs/100 mL, but would be considered an effective interim filtration technology. However, when similar ceramic pot filters were used in a community in Ghana, 99.4% of coliform bacteria was removed from water in communities with houses made of mud and brick, while 90% of coliform bacteria was removed the water of houses made of concrete. This difference is attributable to water that has 400 times less bacteria in the concrete houses (Johnson, 2007). However, it is noteworthy that this study was based on filter use by a researcher rather than community members.

Ultimately, the Sawyer and SAM III have the highest filtration rates, but all filters, at least initially, meet WHO criteria to be considered highly protective household water treatments (WHO, 2011). Practically speaking, filters that remove 99.99% or 99.999% of bacteria are all considered highly protective, and the small degree of difference in filtration of bacteria probably will not result in significant changes in disease incidence (WHO, 2011).

## EASE OF USE: HOW MANY STEPS ARE REQUIRED TO GET WATER TO THE FILTER? HOW EASY IS THE FILTER TO MAINTAIN?

Two main factors determine a filter's ease of use: the number of steps required to get water from water source to the filter, and routine maintenance. All five of the filter technologies are similar in that the user has to physically take a bucket of water from their source and pour it into the top of the filter receptacle. In this case, there is no discernable difference between the different technologies in how the user would interact with the filters.

However, it is important to note that the following factors play a key role in determining the daily steps the user must take to get water to the filter: **water source location** (river, neighbor's yard, own yard faucet), **water storage location** (outside, in the kitchen, next to the filter), and **filter location** (living room, kitchen, bedroom). For maximal ease of use, water should be easily accessible and located as close to the filter as is possible for easy transfer. Because the reviewed technologies are highly mobile, users can move filters to the most convenient location in their homes. These factors are very context specific, and therefore will vary from community to community and household to household. Hence, during the orientation and training process, it is important to discuss ideal location and maintenance for the filter with the person most likely to be in charge of filter use.

***Table 7: Maintenance Comparison across All Filters***

For both the filter part and the bucket system

| | | ONIL | SAM III | Safi | Filtrón | Sawyer |
|---|---|---|---|---|---|---|
| **Ease of Use** | Scrubbing | Ceramic part scrubbed 1/week w/filtered water | Fibrous membrane back flushed after every use w/filtered water* | Ceramic part scrubbed 1/week w/filtered water | Ceramic part scrubbed 1/week w/filtered water and chlorine | Fibrous membrane back flushed after every use w/filtered water* |
| | Turbidity | Turbid water requires more frequent scrubbing | Turbid water requires more frequent scrubbing | Turbid water requires more frequent scrubbing or fabric cover | Turbid water requires scrubbing every other day | Turbid water requires every day flushing |
| | Bucket Cleaning | Bucket system cleaned at least 1/month | Bucket system cleaned at least 1/month | Bucket system cleaned at least 1/month | Bucket system cleaned at least 1/month | Bucket system cleaned at least 1/month |
| | Bucket System | Bucket system could potentially be clear (easily see water level & turbidity) | None | Bucket system is clear (easily see water level and turbidity) | None | Bucket system could potentially be clear (easily see water level & turbidity) |
| | Additional Parts | None | None | Contains a measuring tool for ceramic lifespan | None | Requires outside hose connection for two buckets |

** Based on field test results - otherwise recommended back flush is when filtration rates slow.*

**Maintenance Schedules**

As **Table 7** illustrates, the five filter technologies differ substantially in terms of maintenance relating to scrubbing and turbidity. The ONIL filter and Safi filters must be scrubbed approximately once per week. More frequent scrubbing may be required if the filter is cleaning very turbid water, but the Safi filter also comes with a fabric sleeve to protect the filter from dirt. Unfortunately, this sleeve significantly slows filtration. The SAM III and Sawyer filter must be back-flushed with filtered water when the filtration rate slows. In field tests in Peru, this was necessary after every use (Brune et al., 2013). Most manufacturer materials suggest that back-flushing is only needed approximately once a week, but the majority of tests were performed in recreational waters with low turbidity; back-flushing could be required more frequently for more turbid water (Brune et al., 2013). The ceramic part of the Filtrón filter must be cleaned when it gets dirty. Frequency of cleaning increases with the turbidity of the source water (Duke, Nordin, & Mazumder, n.d.), but is also estimated at about once a week.

**Ease of Maintenance**

For all five technologies, the collection bucket must be cleaned monthly, and all cleaning for any filter components must be done using filtered water and a brush (**Table 7**). In terms of the difficulty of performing maintenance tasks, back-flushing (as is required with SAM III and Sawyer filters) would be easiest since it does not require drainage of unfiltered water and likely takes less time than scrubbing. However, the additional hose connection of the Sawyer filter means that is one more part to monitor and maintain for that filter. While the ONIL and Safi are fairly similar, the Safi filter has a measuring tool to help the user identify when the filter candle needs to be replaced. Additionally, the buckets are clear to help identify water flow and clarity (**Table 7**). For Filtrón, the scrubbing routine requires removal of the ceramic pot from the bucket and the use of chlorine. Lack of access to chlorine may decrease adherence to an appropriate cleaning schedule for the Filtrón filter.

## FILTER FLOW RATES: HOW QUICKLY DOES THE TECHNOLOGY FILTER WATER?

Filter flow rates are significant in that if they are too slow, the technology will fail to provide sufficient filtered water to meet the household's drinking water needs. According to the field usage rates of Biosand filters in Cumaica Norte, families tended to use 40 L of water per day. While the manufacturer flow rates range from 30 L/day to as high as 2,000 L/day (**Table 8**), it is important to note that these flow rate estimates are based on lab tests, likely using less turbid water. The ability to compare rates found in the field is crucial.

***Table 8: Flow Rate Comparison across All Filters***

**Both manufacturer rates and field test rates**

| | | ONIL | SAM III | Safi | Filtrón | Sawyer | Unit |
|---|---|---|---|---|---|---|---|
| **Flow Rate** | Manu-facturer | 40 | > 300 | 40-50 | Up to 30 | Up to 2,000 | L / day |
| | Field | 0.14-0.26 (low turbidity)*<br>0.09-0.24 (high turbidity)* | No Data Found | 0.14-0.26 (low turbidity)*<br>0.09-0.2 (high turbidity)* | 1-2* | 55% (high rate)<br>33% (slow rate)<br>6% (too slow rate) | L / hr. (except Sawyer) |

** Not sufficient daily quantity to meet average household's needs*

Real world conditions and turbidity can have a substantial impact on true filtration rates. As **Table 8** illustrates, only 55% of families reported high flow rates with Sawyer filters; 35% of households reported slow flow rates and 6% stated that flow rates were too slow (Brune et al., 2003). In field tests of ceramic candle filters similar to ONIL and Safi, most filters had a flow rate of 0.14-0.26 L/hr. in low turbidity and 0.09-0.24 L/hr. in high turbidity (Franz, 2005). If that were the case, these filters would not meet household needs. However, these rates are substantially different than rates AMOS has seen with ONIL and Tulip filters and with manufacturer rates.

A Filtrón system is able to filter about 1-2 L/h (Duke et al., n.d.), which is also not sufficient to meet the needs of most households. Hwang (2003) found that on average, over six months of monitoring, Filtrón systems filtered about 1.7 L/hr. This output would not meet the basic water needs of a five-person family[10]. Furthermore, in Yemen, Al-Moyed & Zabara (2008) found that 27% of filters were filtering less than thr.ee liters per day after six months of use. Based on experiences of Biosand filter users, households with 40 L of filtered water daily used it all, so if a filter produces less water, households may choose to use some unfiltered water as well.

## LIKELIHOOD OF CONTAMINATION: HOW EASILY CAN FILTERED WATER BECOME RECONTAMINATED?

Once water has been filtered, it is imperative that it is not re-exposed to contaminants. Some of the filters examined are more prone to re-contamination than others (**Table 9)**.

***Table 9: Likelihood of Recontamination Comparison across All Filters***

Both manufacturer rates and field test rates

| | ONIL | SAM III | Safi | Filtrón | Sawyer |
|---|---|---|---|---|---|
| **Likelihood of Recontamination** | Likely | Least Likely | Likely | Highly Likely | Less Likely* |
| | (frequent handling) | (1-bucket system) | (frequent handling) | (frequent handling and overfill) | |

** Field test rates based on a 3-bucket system, which increases likelihood. AMOS would just use a 2-bucket system.*

The filtration rate of the thr.ee ceramic filters (ONIL, Safi, and Filtrón) is often quite slow, sometimes to the point that the filter cannot meet the household's drinking water needs. As a result, real-world use of the Filtrón filter often leads to overflow. Users may wish to fill the filter less frequently and try to overfill the filter. Overfilling the filter results in contaminated water mixing with filtered water. This means that ultimately only 50% of bacteria is removed from "filtered" water (Baumgartner, 2007). Also of note is the fact that the Filtrón ceramic piece must be removed frequently for cleaning. This frequent handling further increases the possibility of recontamination (Duke et al., n.d.). Thus, these thr.ee filters are rated the most likely to have recontamination problems (**Table 9**).

In a field use study of candle filters in Ghana, recontamination rates were at 79% (Ziff, 2009). However, this system used an open-collection container, which increases the risk of recontamination. In fact, the safe collecting system recommended by the author greatly resembles the ONIL and Safi systems, with a closed-collection system and a spigot to avoid handling water in the container (Ziff, 2009).

In field studies of Sawyer filters, water was collected directly from the filter. Brune et al. (2003) found wide variations in the amount of recontamination from community to community, with one site experiencing contamination as low as 13%, and another site with 100% recontamination. On the whole, contamination rates were in the range 40-50% (Brune et al., 2003). The system tested did utilize a thr.ee-bucket system, thus introducing an additional layer of potential recontamination. Similarly, Kohlitz et al. (2013) found that even in water taken directly from the filter, only 29% was not re-contaminated and 54% was highly re-contaminated.

[10] While in theory the lower cost of the Filtrón makes it possible for multiple filters per household, in reality this option does not fit in with AMOS's programming model.

No field tests for the SAM III system were found. Because the system is confined to one bucket and a storage container, presumably contamination would be less likely (**Table 9**).

## Durability: What is the average break time and lifespan of filters?

Filter breakage is a major driver of discontinuation of filter use, particularly if replacement parts are not readily available or if it is unclear how to obtain them. Using filters that are easily broken during transport also substantially increases the cost of implementing a project, as many of the purchased filters, if broken, will not be usable upon arrival to site. Even small cracks in ceramic filters can render them useless as bacteria and parasites will be able to pass through.

***Table 10: Durability Comparison across All Filters***

How breakable are the filters - breakage rates used in the CCA* - lifespan

| | | ONIL | SAM III | Safi | Filtrón | Sawyer |
|---|---|---|---|---|---|---|
| **Durability** | Rating | Somewhat Breakable | Least Breakable | Highly Breakable | Highly Breakable | Less Breakable |
| | (Reasoning) | | | | | |
| | Reasoning | (porous from silver nanoparticles, no cement, thicker than Safi) | (1-bucket system) | (porous from silver nanoparticles, cement prone to cracking, thin) | (large ceramic pot, porous from silver nanoparticles) | (connection hose) |
| | Breakage Rate | 5%, 5% | 5%, 5% | 7%, 7% | 15%, 5% | 5%, 5% |
| | Lifespan | 1 yr. | 10 yr. | 1 yr. | 1 yr. | 20 yr. |

** These are the breakage rates use in the PPA section: breakage rate during transport, breakage rate in use.*

The Safi filter is made in India, of white kaolin clay; an estimated 18 million filters are produced each year (Murcott, 2006). The major concern with these filters is quality. The manufacturing process involves putting white cement between the candle and the cap, which can lead to cracks and leaks (Murcott, 2006). The particular Safi filter currently distributed in Nicaragua was designed after Murcott evaluated Indian filters, and likely would not be included with his categorization of lower quality filters. Silver impregnation makes these filters more effective, but also more fragile than standard candle filters. Specific breakage rates could not be found, but given that even small cracks render the filter useless, it is likely quite high. Hence, this filter received the highest rating for breakability (**Table 10**).

Because the ONIL is also a silver-impregnated ceramic candle filter, breakage rates are likely similar, but may be slightly less because of the larger size and thicker ceramic (**Table 10**).

Filtrón filters are impregnated with silver nanoparticles, which requires more highly porous material and increases the filter's fragility. These filters were monitored in the field for six months in San Francisco Libre, Nicaragua. During these six months, there was a 15% breakage rate, and about a 5% breakage rate during delivery (Hwang, 2003). These breakage rates occurred in a situation with monthly monitoring, so one may assume that without such monitoring, breakage rates may trend even higher. Similarly, the maintenance routine requiring frequent removal and handling of the ceramic pot increases the possibility of breakage (Duke et al., n.d.). As such, Filtrón filters are also rated as highly breakable (**Table 10**).

In Peru, a group piloted Sawyer filters for six months. One filter out of 39 developed a leak (Brune et al., 2003). They found that 94% of respondents found the filter easy or very easy to use. Only one out of 43 households reported that the filter did not always work. A major barrier to continued use was the ability to obtain alum for use as a coagulant to reduce the impact of turbidity on the filters. In a study of Sawyer filters in Fiji, 22% of filters were found to have broken or missing parts over the course of thr.ee years, and among those who received their filter in the first year, 32% were no longer functional (Kohlitz et al., 2013). This variation in breakage rates is difficult to reconcile given the small number of field tests performed thus far. Because parts for these filters come from the US, it may be safer to assume a higher breakage rate to ensure that necessary parts are on hand. However, in comparison to the ceramic type filters, Sawyer is rated less breakable (**Table 10**).

Although literature on breakage rates for SAM III filters was not found, because the technology is similar to that of the Sawyer filters, we can assume the likelihood of SAM III breaking is also similar. Notably, the Sawyer filter system is composed of 2 buckets and a hose connecting the buckets (**Figure 10**), while the SAM III is composed of a 1-bucket system that has no external components (**Figure 8**). Having an exposed connection hose means that the Sawyer filter may be more prone to breakage than the SAM III, so it is also rated as less breakable (**Table 10**).

As for filter lifespan (assuming they do not break), the SAM III and Sawyer are extremely durable in comparison to the other filters, and have been estimated to last for ten and 20 years (respectively). This is due to the nature of the technology, as hollow fiber membranes last much longer than ceramic. The other thr.ee ceramic filters only last for one year reliably before their efficacy diminishes.

## PORTABILITY: HOW EASILY CAN THE FILTER BE MOVED FROM ONE LOCATION TO ANOTHER?

Based on our discussions with residents of Cumaica Norte, portability was a major factor in continued use of a filter. Heavy filters often broke in transport unless many people were gathered to move them. Some users also wished they were able to move the heavier Biosand filters. All five of the filters we evaluated within this report are lightweight and easy to move. However, amongst them, Filtrón is the heaviest, with its large, fragile ceramic pot. It is therefore rated as only somewhat portable (**Table 11**). The other ceramic filters (ONIL and Safi) are more likely to break while being moved than Sawyer and SAM III; hence these ceramic filters are rated portable as opposed to very portable, which is what the SAM III and Sawyer are rated (**Table 11**).

*Table 11: Portability Comparison across All Filters*

Comparing ease of moving filters from one location to another

| | ONIL | SAM III | Safi | Filtrón | Sawyer |
|---|---|---|---|---|---|
| **Portability** | Portable<br><br>(lightweight - fragile parts) | Very Portable<br><br>(lightweight) | Portable<br><br>(lightweight - fragile parts) | Somewhat Portable (heaviest - very fragile parts) | Very Portable<br><br>(lightweight) |

## REPLACEABILITY: HOW EASILY CAN THE FILTER AND ITS VARIOUS PARTS BE REPLACED?

Communities must be able to access replacement parts in order to continue using their filter after it breaks or otherwise needs to be replaced. This need is particularly acute in filters with shorter lifespans. In these cases, a well-established replacement plan must be in place or filters will quickly fall into disuse as filter flow rates decrease and filter efficacy decreases.

*Table 12: Replaceability Comparison across All Filters*

Comparing ease of replacing the main filter part

| | ONIL | SAM III | Safi | Filtrón | Sawyer |
|---|---|---|---|---|---|
| **Replaceability** | Distributor located about 50 km from Managua (Masaya)<br><br>(Made in Guatemala) | No distributor<br><br>(Shipped from U.S.) | Distributor in Managua - Supply not fully established but confident can maintain supply<br><br>(Shipped from India) | Manufactured and distributed in Nicaragua<br><br>(Jinotepe) | No distributor - Various other NGOs distributing in Nicaragua<br><br>(Shipped from U.S.) |

In **Table 12**, the distributors and shipping locations are compared across all five filters. An ONIL filter distributor is located in Masaya, about 50 kilometers from Managua. The Filtrón factory is also located in Nicaragua, in Jinotepe, but we have had little success in communicating with representatives of Filtrón within our investigation. While in country conducting field research, we discovered that the founder of Filtrón recently passed away, and a mechanism for maintaining the administrative end of the business was not in place. Filtrón is the only filter that is manufactured in Nicaragua rather than shipped in.

The distributor of Safi filters is located in Managua though the filter mechanism itself is made in India. The distributor reports that they initially ordered 1000 from India, but has not yet distributed that initial supply. They are confident they will be able to restock as needed, but a well-established supply chain has yet to be developed. He also reports that filter parts could be delivered to villages, though he was unable to provide a quote for the cost of delivery. Because of the presence of a distributor in Managua, Safi filters are likely the easiest filters to replace.

There are thr.ee NGOs located in Nicaragua that distribute Sawyer filters (Sawyer International, 2014). The exact location of these organizations was not specified, and it appears that the filters are shipped in from the U.S. While these NGOs are not officially distributors, they could play a role as a partner in filter acquisition. For all practical purposes, it appears that any Sawyer replacement parts would also need to be shipped from the U.S. Due to the transport process, it could take weeks or months to replace filter parts, unless extra parts are kept on hand in Nicaragua.

SAM III must also be sent from the U.S., and has replacement problems similar to Sawyer filters.

## Potential for Business opportunity: How much potential do the filter and supply chain have with respect to a local business model?

If filters are to be distributed by way of a market mechanism (**see Section 8**), filters that require more frequent replacement will make for a more viable business opportunity. In small villages, it is unlikely a businessperson will be able to create and maintain a supply chain if a filter is only replaced every 10-20 years. **Table 13** rates the five filters in their potential to facilitate turning the replacement and maintenance into a business opportunity for a community member.

***Table 13: Potential for Business Comparison across All Filters***

| Frequency of Replacing Parts for a Market Model Business | ONIL | SAM III | Safi | Filtrón | Sawyer |
|---|---|---|---|---|---|
| Potential for Business | High Potential<br><br>(Distributor in Nicaragua; Requires annual filter replacement) | Low Potential<br><br>(No local distributer; Only replace filter mechanism every 10 years) | High Potential<br><br>(Distributor in Nicaragua; Requires filter replacement every 3 months) | Some Potential<br><br>(Manufactured and distributed in Nicaragua; Replace every year) | Low Potential<br><br>(No local distributer; Approximately 20 year lifespan) |

The Safi filter must be replaced thr.ee times each year, which gives the filter high potential (**Table 13**). The ONIL filter also requires annual replacement, making it another filter with high potential. The Filtrón filter lasts 2-4 years, but should be replaced annually for efficacy preservation; meaning it also has some potential for business opportunity. SAM III filters last ten years. Sawyer filters are reported to last for 4,000,000 liters; based on this estimate, we approximated at least 20 years of use. As such, both have low potential for business opportunity.

With distributors in Nicaragua and frequent replacement cycles, Safi and ONIL filters provide the most viable business opportunities for a community member (**Table 13**).

## Discussion

Key determinants of which filters to choose extend well beyond cost alone. An affordable filter does no good if no one will use it. Two other factors are key to long-term usage. First, **can the filter realistically be used in a home in a way that will effectively prevent disease?** Second, **is the filter easy enough to use that households will continue using it?** In the factors examined above, efficacy, likelihood of contamination, durability, and replaceability all contribute to the probability of effectiveness of the filter (**Figure 17**). Probability of sustained use is determined in large part by ease of use, filter flow rates, durability, portability, and replaceability (**Figure 18**). To a much smaller extent, continued use may be influenced by potential for business opportunities, as a business owner may take up some advertising and community mobilization to ensure continued demand for their product.

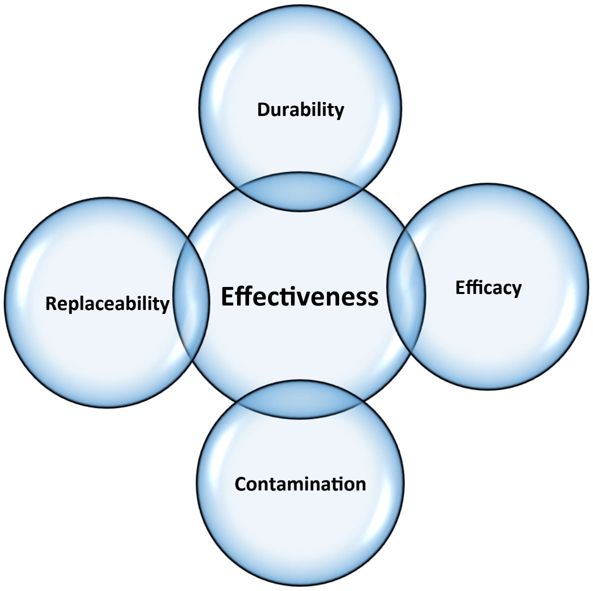


***Figure 17: Factors of Filter Effectiveness (also Fig. 1 in Executive Summary)***

*Note 3: Same as Figure 2 in Executive Summary*

**Effectiveness**

As mentioned above, the Sawyer filter and the SAM III filters remove the highest percentage of bacteria. The extent to which the differences in bacteria removal affects actual disease rates remains unclear. Similarly, the set-up of both the SAM III and Sawyer filters makes them less likely to contribute to recontamination. All of these filters, however, make use of closed bucket tops that are easy to clean and help in preventing contamination. They also have a spigot to dispense water, thus eliminating the need for any hands to be in the collection container. SAM III and Sawyer filters are the most durable, but also the least replaceable. If either of these filters breaks, it will not be used, and consequently ineffective (Safi, Filtrón, and ONIL are all quite easily replaced from within Nicaragua). On the whole, the SAM III and Sawyer filters are most likely to be effective.

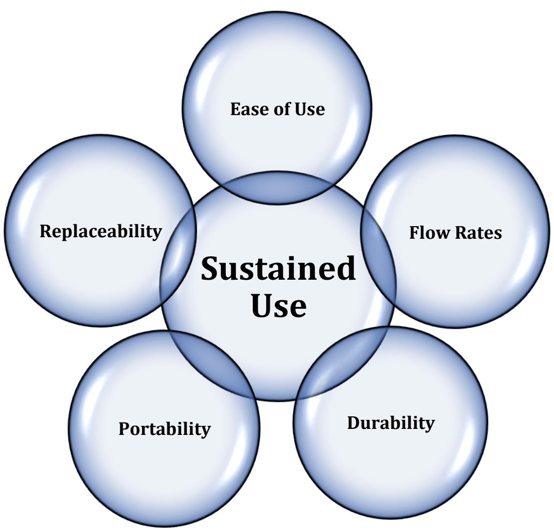


***Figure 18: Probability of Sustained Use***

*Note 4: Same as Figure 3 in Executive Summary*

**Sustained Use**

In order for a household to continue using their filter, filter use and maintenance cannot significantly interfere with the completion of other necessary household tasks. The SAM III and Sawyer filters are easiest to use are since back-flushing is easier than scrubbing. Otherwise, care for SAM III, Sawyer, ONIL, and Safi is similar. A filter's flow rate is also a critical determinant in whether or not a household will continue to use it. If a filter cannot produce enough water to meet household needs, families are likely to stop use of the filter or intermittently use unfiltered water. Both Sawyer and SAM III's ability to filter water vastly exceeds a household's daily needs. ONIL and Safi typically can meet household daily needs (at least 7L per person per day), but in settings with highly turbid water, these rates are likely to decrease substantially. Flow rates for Filtrón decrease substantially with use and typically initially produces about 30 L per day. Even initially, this would not be sufficient for a family of five. SAM III and Sawyer filters are made of plastic and have very long life spans, so they are least likely to break during use. Their plastic composition also makes them lightweight and easy to move to a new location both within and between houses. However, replaceability is again a major issue for both filters. If these filters were used in communities, a stockpile of filter parts would likely need to be distributed as well, to ensure that users have adequate access to replacement parts.

Overall, if AMOS foresees remaining in the communities indefinitely, the SAM III and Sawyer filters are most likely to be used effectively and to see sustained use. In order for these filters to have a lasting impact, a clear plan for obtaining and distributing replacement parts must be in place prior to implementation. On the other hand, if AMOS prioritizes local availability, then the ONIL filter is the best overall filter choice. We will go into more depth regarding different value-models and their recommended filters in the conclusion of this report.

# Framework for a Market Model

## Introduction

One component of a successful development initiative is the program's continued functioning long after the intervening agency or organization has moved on. In the context of AMOS's point-of-use water filter project, this would mean that filter use and maintenance would continue in beneficiary communities after AMOS has stopped organizing and bearing the cost for filter provision and maintenance. One way to create this sort of long-term sustainability would be to create a market-based model for filter provision and maintenance. Though AMOS has not considered building their household water filter programs in this fashion, such a model would allow for increased development of a local supply chain and a system in which local técnicos are accountable to the local population rather than to AMOS alone. In looking long-term at this countrywide project, the authors felt it important to introduce this framework as an option for AMOS to consider in their long-term planning. In building in a mechanism to transition to community management, AMOS can allocate attention and resources to other areas of health programming.

Market-based technological interventions rely on market pressures of supply and demand to drive their sustainability. They create a demand for the intervention by emphasizing the product's utility to consumers (increasing benefits or reducing costs through the intervention). At the same time, an available supply of the intervention product and necessary maintenance creates an income generating opportunity for entrepreneurs to promote the intervention.

In the case of the filter project, a market-based model of intervention would promote the importance of using a water filter due to reductions in disease among users. Diarrheal disease not only causes increased health care costs for a family, but also results in decreased wage earning and lost productivity in household work as well. Filter users could even sell excess filtered water to neighbors without a filter. Entrepreneurs can become filter purveyors and maintenance experts (in the vein of a plumber) who would benefit from seeing that filter use is as wide-ranging throughout the market as possible and that filters are regularly maintained (as this results in a higher profit for the entrepreneur).

## Model

In the market-based model we propose that filter maintenance and repair be provided by a técnico, who offers his or her services for a fee. In this scenario, s/he makes a profit by offering repair services, building in an inherent interest in providing repairs and filter upkeep, as the técnico's income is now tied to the amount of services provided. This model also creates a system of accountability, since the households owning filters make the decision to pay the técnico based on whether or not s/he completes the repair services to their satisfaction. Such models, however, do not automatically occur in a community because:

- The benefits of the filters must be valued,
- A person must be willing to be the entrepreneur,
- The filter parts must be readily available, and
- A system of payment and accountability must be valued at the household level.

AMOS's water filter program already addresses educational awareness and capacity building of community members, creating an understanding of and a value for the benefits that filtered water provided. A subsidy system for the service fees can also be put into place in such a way that AMOS can aid the transition to this market model without disrupting the final market model (which requires

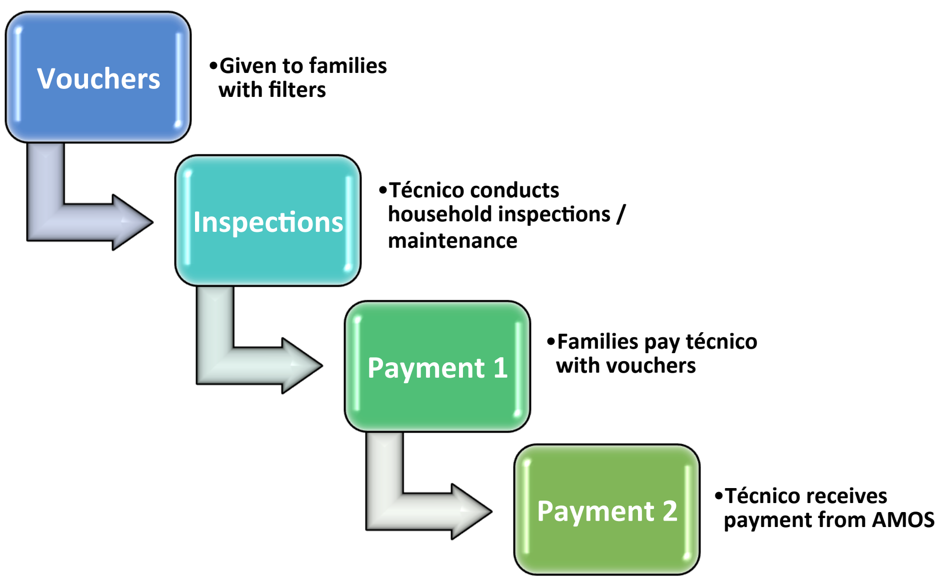


*Figure 19: Subsidy Framework for Filter Service Fees - A Way to Transition to a Market-Based Model*

técnico accountability to the families rather than to AMOS).

Initially, AMOS[11] could give each "client" (household) a voucher that will essentially cover the cost of paying the técnico for filter maintenance. They would give this voucher to the técnico once s/he fixes the filter. The técnico doesn't receive monetary payment until s/he brings the vouchers to AMOS -

[11] Another scenario for this would be to have the Nicaraguan Ministry of Health support the model with funding while AMOS would administer the intervention. Although we are unsure of how feasible this option might be for AMOS to advocate for, we thought it worth mentioning as it would foster accountability at the national level.

receipt of the vouchers becomes necessary for the técnico to receive payment. So in this system, the técnico must please the client with their services in order to receive "payment." Accountability for filter maintenance and its quality now comes from the filter users themselves–who give their voucher to the técnico only after they deem the services rendered as quality–rather than relying on AMOS to be responsible for filter maintenance. Shifting the accountability from AMOS directly to filter users ensures greater sustainability of the project.

This voucher system would be a short-term system to help transition from AMOS accountability for filter maintenance to client-based accountability. In the long term, as quality filter maintenance becomes an established routine within the community, AMOS would slowly phase out the voucher-for-services system, transitioning away from giving the vouchers to households in favor of incrementally increasing the price households pay to obtain vouchers. Eventually, households will pay a price for the vouchers that are equivalent to what AMOS pays to the técnico for his or her services--at this point, the voucher system can be removed in exchange for direct payment from filter users to the técnico.

Besides filter maintenance, filter provision will ideally also become a market-based intervention. AMOS currently subsidizes the cost of providing filters to households; the $20 "buy-in" that families provide for receiving a filter does not cover the filter's total cost. Until the benefits of filtered water become established in the community, and community members come to accept the value of owning and using a water filter–whether those benefits come from averted healthcare costs, less productivity lost due to illness, income from selling filtered water or others–AMOS will continue to need to subsidize the introduction of water filters. Eventually, as the value of a water filter becomes established, people will seek to purchase and use filters independent of encouragement from AMOS, leaving AMOS free to focus on other programming areas.

## Discussion

Establishing a model of market-based intervention is not a panacea for the challenges of creating a sustainable water filter project. The key to any market intervention is that people recognize the benefit of using the technological innovation and are therefore willing to pay in order to have it. Creation of the "value" for the intervention takes time, and until that value is established, having an NGO to continue subsidizing the costs of the intervention is important.

In the case of AMOS's filter project, anecdotal evidence suggests that many people do not recognize the benefits of using a water filter until a catalyzing event takes place - such as a disease outbreak or contamination of source water that somehow makes the benefits of using a filter readily apparent. AMOS can act upon these events as "windows of opportunity" to promote the benefits of water filters. This calls for situational awareness and responsiveness to community context. If AMOS decides to pursue a market-based model for its filter interventions, continued but gradually decreasing subsidization of filter provision and maintenance will be important to ensure that people do not stop using filters altogether. Without NGO support, people may get lost in the gradual transition from NGO-supported to market-based interventions. Other advantages and disadvantages of a market-based model are explored in **Table 14**.

*Table 14: Trade-offs of the Market Based Interventions Model*

| | Advantages | Disadvantages |
|---|---|---|
| Entrepreneurship | May create profitable local enterprises (manufacturing and distribution) that will contribute to the economic sustainability of the technology and benefit the local economy | May lead to poor quality of filters are producers compete to increase production to meet demand, or as copycat manufacturers enter the market. Quality control is an essential element to manufacturing, very much open to abuse. Note: there is no feedback available to users to check microbiological effectiveness of their filters. |
| Accesibility | Possible to reach a large proportion of the population, quickly and relatively inexpensively compared to other water quality improvements | Users may not get the education and training needed to ensure proper use of the filter |
| Awareness | Local vendors ensure that parts, replacements, and knowledge of the filters are available | Unscrupulous vendors or manufacturers may claim effectiveness of the filter against chemical contaminants, notably arsenic and pesticides; vendors are not educating but advertising |
| Stakeholder Buy-In | Cash investment in the filter is associated with longer and more conscientious use of the technology | The poorest will likely be unable to afford full-price filters |
| Sustainability | Can sell to other NGOs and government agencies, who can use filters as part of their own WSH programs, increasing coverage | Other entities distributing the filters may do so irresponsibly (e.g., giving them away to those who can pay), and therefore maybe counterproductive to sustainability |

*Source: Brown, J., Sobsey, M. & Proum, S. (2007). Use of Ceramic Water Filters in Cambodia. Water and Sanitation Program, UNICEF. Retrieved from: http://www.unicef.org/eapro/WSP_UNICEF_FN_CWP_Final.pdf*

# RECOMMENDATIONS

Based on the above analyses, both cost comparison and feasibility, as well as our understanding of the context in which AMOS is working, we have identified four different value-models for determining which filter to recommend.

5) If **Local Availability** is highly valued: **ONIL**
6) If **Ability to Transition to Community Filter Management** is highly valued: **ONIL**
7) If **Ease of Use** is highly valued: **SAM III**
8) If **Affordability** is highly valued: **Sawyer**

Within each model, we determined the top thr.ee filters that best meet the valued attribute, and then determine, of these three filters, the top filter in terms of cost, efficacy, and sustained use, each.

## WHY THESE FOUR SCENARIOS?

Before going into detail regarding these four value-models, it is first important to understand why we chose these four models to begin with. Below we outline why each attribute is considered important to AMOS's programming.

**Local Availability**

- If the filter parts come from abroad, users may wait weeks to months for replacement parts.

- Users must know how to get filter parts and keep filters working when AMOS leaves a community.
- Local purchase of filters has the added benefit of fueling local economy.

**Ability to Transition to Community Filter Management (Self-Maintaining Systems)**
- The need for clean water continues even if AMOS is unable to continue in a community.
- Transitioning out of a community allows AMOS to direct its resources to others in need.
- Long-term community buy-in and ownership of the project is necessary for a lasting impact.

**Ease of Use**
- Families have many competing demands on their time, and the more difficult it is to use, the less likely they are to make the time.
- Systems to find replacement parts in remote communities are difficult to navigate, if they exist.
- The easier filters are to use, the less likely the water is to be recontaminated.

**Affordability**
- The more a filter costs, the less money is available (within AMOS) for other programming.
- AMOS will likely have to subsidize more expensive filters for a longer period of time. People will not be more willing to bear the full cost of an expensive filter, delaying the transition to community management.
- If communities are ultimately to take over maintenance expenses, they are less likely to have the resources to maintain the more expensive options.

## LOCAL AVAILABILITY VALUE MODEL

**Which filters have the most reliable local availability? (Figure 20)**

**ONIL** has the most reliable local availability. There is an existing relationship with the manufacturer and the distributor.

**Safi's** distributor is in Managua, making it easy for AMOS to connect with him and deliveries of filter parts are free in Managua. However, the filter is shipped from India. There has been one shipment of 1000 filters thus far, so the supply chain is not yet well established. The distributor is confident he will be able to maintain an adequate supply.

**Filtrón** is the only filter made in Nicaragua. However, the founder passed away in 2008. Since that time, there have been increasing communication challenges in making orders.


***Figure 20: Local Availability - Comparison across Top 3 Filters***

**Attributes of filters that are best in terms of local availability:**

1) **Cost**: ONIL is slightly more affordable than Filtrón over the duration of the project $147,000 versus $149,000
2) **Efficacy**: All of the top thr.ee filters have similar original efficacy. Filtrón has been shown to decrease in effectiveness over time (90% at 4 years). Filtrón is also the most likely to be re-contaminated because of frequent handling to clean the filter and the risk of overfilling the filter.
3) **Sustained Use**: ONIL and Safi filters involve the same maintenance steps. Safi is slightly easier because it can be cleaned within the bucket system. ONIL may be slightly less breakable because of its larger size. Both of these are scrubbed with a brush, whereas Filtrón must be removed from the filter system and cleaned with chlorine.

***Recommendation based on local availability: ONIL***

## Ability to Transition to Community Filter Management Value Model

**Which filters are the best for this? (Figure 21)**

Filters that are replaced more often lend themselves best to a potential market model, as filters that are replaced every 10-20 years will not be a profitable business opportunity in small communities.

Local availability of filter mechanisms is necessary for transition out of the community, as villages are unlikely to be able to contact a manufacturer in the US and arrange delivery to a remote village.

Because both short lifespan of the product and local availability are key to transition out of the community ONIL, Safi and Filtrón again are the best options.

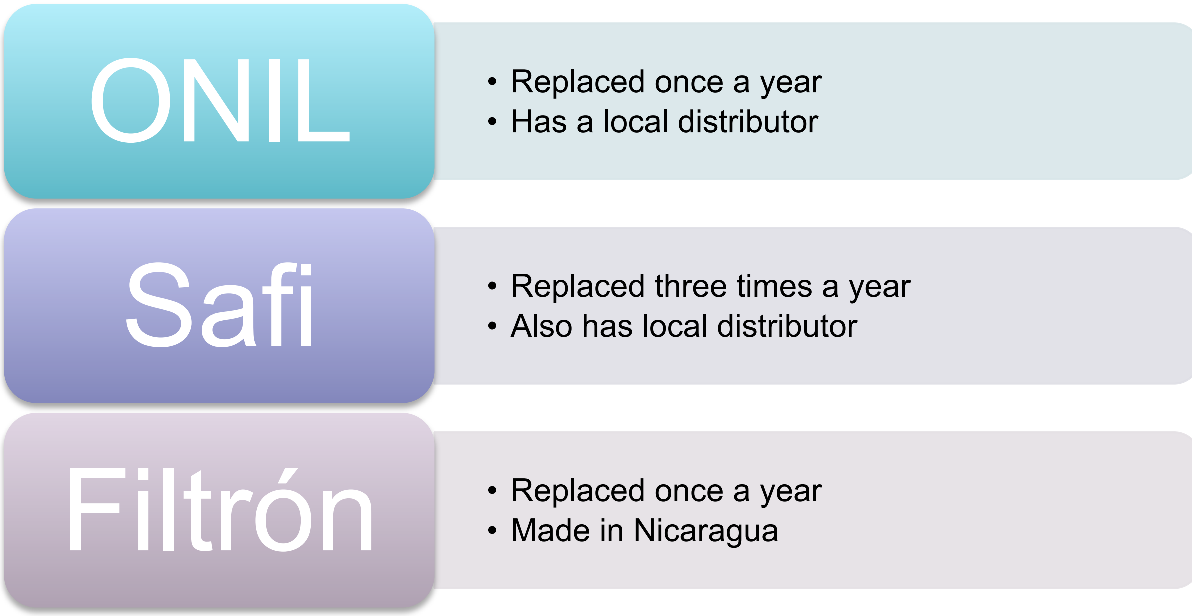


*Figure 21: Ability to Transition to Community Management - Comparison across Top 3 Filters*

**Attributes of filters that are best in term of autonomous use and maintenance?**

1) **Cost**: As noted above ONIL is slightly more affordable than Filtrón
2) **Efficacy**: As above, ONIL and Safi are similar in terms of efficacy
3) **Sustained Use**: As above, ONIL and Safi are similar in likelihood of sustained use, with Safi easier to clean, but ONIL requiring less frequent replacement

***Recommendation based on ability to transition to community filter management: ONIL***

## Ease of Use Value Model

**Which filters are easiest to use? (Figure 22)**

Because the only maintenance that SAM III and Sawyer filters require is flushing a syringe of filtered water back through the filter as needed to maintain flow rates (this varies from every use to weekly), it is easier to maintain than the other filters that require scrubbing. All of the filters require monthly sterilization of the collecting bucket. SAM III and Sawyer filters also have a longer lifespan and are more durable, so users are less likely to need to find replacement parts.

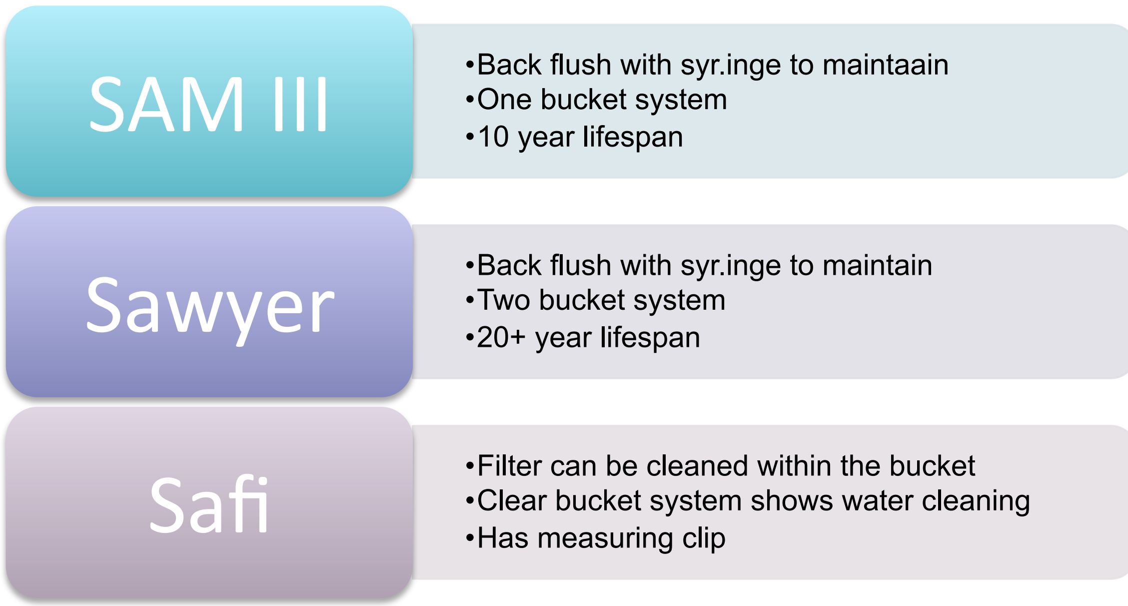


*Figure 22: Ease of Use - Comparison across Top 3 Filters*

**Attributes of filters that are best in terms of ease of use:**

1) **Cost**: Sawyer filter is slightly cheaper than SAM III, $3000 cheaper over 20 year duration of project
2) **Efficacy**: Sawyer filter may be able to filter out more bacteria, but the difference is unlikely to affect real world disease rates.
3) **Sustained Use**: SAM III filter is easier to use because the one-bucket system is easier to maintain and because the filter being located inside of the bucket makes it less breakable.

*Recommendations based on ease of use: SAM II*

## Affordability Value Model

**Which filters are most affordable? (Figure 23)**

***Sawyer*** is the cheapest at a net present value of almost $68,000 over the span of the 20-year project.
***SAM III*** is fairly close behind at a net present value of about $80,000.
***ONIL*** is much more expensive, almost double Sawyer filter cost, at about $147,000 net present value.

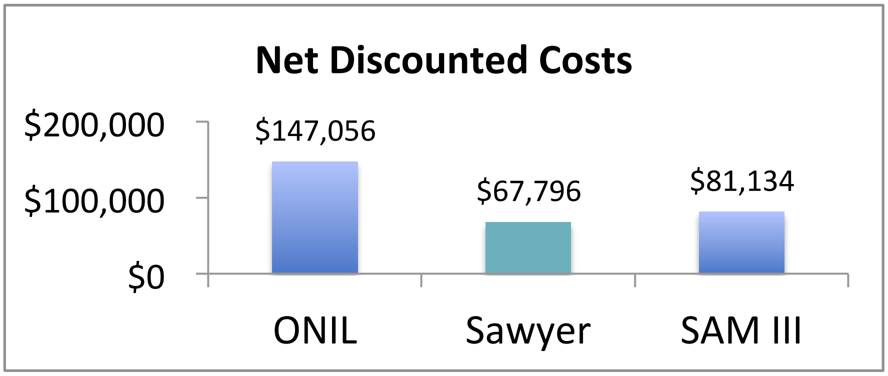


*Figure 23: Cost Comparison of Thr.ee Most Affordable Filers*

**Attributes of filters that are most affordable**

1) **Cost**: As noted above, the Sawyer filter is $3000 cheaper than SAM III over the 20 year duration of the project in our base scenario
2) **Efficacy**: As noted above, no meaningful difference between the two filters
3) **Sustained Use**: SAM III is somewhat easier to use and less breakable than the Sawyer filter

*Recommendations based on affordability: Sawyer*

## OTHER FACTORS TO DEVELOPING PROGRAMMING PRIORITIES

- **Water source location** (river, neighbor's yard, own yard faucet), **water storage location** (outside, in the kitchen, next to the filter), and **filter location** (living room, kitchen, bedroom) are crucial factors in ease of use and consequent uptake of water filters – the more convenient a filter is for user, the better.

- Adjustments to how health promoters in the community **illustrate the number of children with diarrheal illness** could convince community members of the importance of water filtration if measurement methods account for the presence of filters. **Disaggregating the data** to be able to compare families with filters and those without could have an important impact.

- **Breakage in use will affect the cost of the project much more substantially** than breakage in transport. The importance of reducing breakage rates in use becomes clearly evident, and suggests that investment in educating filter recipients on proper filter handling and maintenance will yield financial gains.

- **Changes in transport costs will drive up costs much faster** than changes in filter prices, so if AMOS has to deliver filters to the community and transport prices go up, local availability (but shorter lifespan) of filters may be less of a priority. Because of the large portion of total program expenditures dedicated to transportation, filters that require less frequent replacement and repair become even less expensive.

- Efforts to perform **multi-purpose trips** to the community and **transition to community** management and maintenance of filters would **provide substantial cost savings.**

- Development of a market model for filter provision and maintenance would **provide a transition of filter responsibility to community management**, ensuring filter use sustainability after AMOS ends its involvement with the filter program.

## FINAL THOUGHTS

No filter is clearly head and shoulders above the rest. Communities will have to determine for themselves which priorities matter most in consultation with AMOS. AMOS's current programming plan to pilot ONIL and SAM III filters is very reasonable given their priorities and the information gathered in our analyses.

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# APPENDICES

## A. COMPARISON OF WATER FILTER TECHNOLOGIES: BENEFITS AND DRAWBACKS

| Filter Type | Benefits | Drawbacks |
|---|---|---|
| **Potters for Peace (Ceramic)** | Produced locally (Filtrón) | Breaks easily |
| | Effective bacterial removal (Filtrón with silver nanoparticles) | Requires regular cleanings |
| | Easily transported | Requires regular water input for best flow rates – tend to be slow, especially if clogged |
| | Cost effective | Relatively short life-span (2-3 yrs.) |
| | Parts easily replaced | Not effective against smaller viruses |
| | Familiar technology – more easily accepted | Effectiveness decreases over time |
| **Hydraid (Biosand)** | 95% reduction in E. coli load | Heavy and immobile (140 lbs.) |
| | 47 L / hr. flow rate, serves 8-10 people daily | No parts are locally sourced |
| | Filter media pre-bagged & supplied w/ purchase | Efficacy highly dependent on proper maintenance (filter must be filled intermittently) |
| | Few parts for replacement | 59% reduction in diarrheal disease |
| | Easy to use & familiar technology | $60 per unit, $850 for pallet (15) |
| | 10 year lifespan | |
| **ProCleanse** | High flow rate (6-20 L/h) | Expensive (based on 10 year production of 180,000 L at $0.001 L, would be $180) |
| | Built in safe storage container | Entire technology obtained from U.S. |
| | Only requires maintenance 3-4 times per year | |
| | Lifespan of 10 years | |
| **Nutshell** | Nutshells comparably inexpensive as adsorbent material | Not designed for household/POU |
| | Organic materials readily available | More commonly used with water in refineries and industrial settings |
| | Less adsorbent required than commercial filters for same effect | |