# POSSIBILITIES FOR THE RE-COLLECTION AND RECYCLING OF LONG-LASTING INSECTICIDE-TREATED NETS (LLINs) IN SUB-SAHARAN AFRICA

By

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## Abstract

The United States Agency of International Development (USAID) and the World Health Organization (WHO) have relied heavily on the distribution of bednets to curb malaria in sub-Saharan Africa. Additionally, WHO has recently recommended a massive scale-up of its distribution of long long-lasting insecticide-treated nets (LLINs). Many nets in circulation are already reaching their end-of-life stage, and with more nets on the way USAID and WHO are concerned that discarded nets will have negative impacts on both the environment and human health. This master's project addresses two issues of concern for USAID's LLIN technical team: 1) whether a disposal/recycling program is a possibility for manufacturers and donors, and 2) whether there are realistic possibilities for retrieving nets from the field after they have lost their efficacy. Research on these issues was conducted through a literature review and a series of interviews with manufacturers, donors and other stake-holders.

Results indicate that take-back and recycling programs could be a possibility. Manufacturers are receptive to the idea of more environmentally friendly practices including recycling old nets and using biodegradable packaging. They are also continuing to develop technology to make recycling nets a possibility. Additionally, the World Bank's estimate for cost of recycling programs is feasible for donors at this time. Existing recycling programs in developing countries have also provided models of successful examples for take-back programs in sub-Saharan Africa. They highlight the importance of education and the value of using existing infrastructure for sustainable programs with high success rates.

## Introduction

*Malaria in Sub-Saharan Africa*

Researchers estimate that malaria kills between 2 and 3 million people worldwide every year, (Uneke et al. 2007) and its transmission continues to increase globally (Opreh et al. 2008). Of these deaths around 90% occur in sub-Saharan Africa (Uneke et al. 2007).

Although malaria is a curable and preventable disease, Africa continues to sustain this high disease burden for a host of reasons. First, the disease is caused one of four human malaria parasites of the genus *Plasmodium*, with the most virulent strain, *Plasmodium falciparum,* causing the majority of infections in sub-Saharan Africa (Uneke 2008). Second, a large portion of this region consists of tropical areas where the malaria mosquito vector thrives (Sachs and Malaney 2002). Additionally, the mosquito vector responsible for most disease transmission in sub-Saharan Africa, *Anopheles gambiae*, is thought to be the most effective malaria mosquito vector, in part because it is difficult to control (Uneke 2008) and in part because it has a strong affinity for biting humans (Sachs and Malaney 2002). These factors in addition to drug-resistance, poverty, malaria's interaction with other diseases, unstable political structures, lack of sufficient healthcare and other obstacles create a deadly situation when it comes to fighting malaria in this region of the world (Sachs and Malaney 2002).

The relationship between malaria and HIV/AIDS has received considerable attention recently, especially in Africa. Across the continent HIV rates have skyrocketed over the past 25 years, leaving large numbers of the infected with an increased risk of malaria-related deaths, especially in patients with advanced immunosuppression (Korenromp et al. 2005). HIV has been found to increase cases of severe malaria, malaria case fatality rates and failure rates of anti-malarial treatments (Korenromp et al. 2005). The HIV epidemic is blamed for a 1.3% increase in malaria incidence and a 4.9% increase in malaria deaths within sub-Saharan Africa (Korenromp et al. 2005). [1]

Subpopulations especially vulnerable to malaria infection include children and pregnant women. Children account for 90% of the life-threatening cases in sub-Saharan Africa (Opreh et al. 2008), and an African child dies of the disease every 30 seconds (Zhuang et al. 2008). Additionally, pregnant mothers are highly susceptible to malaria infection because of a temporary depression in their immune systems' defenses (Uneke 2008). Once a pregnant woman has malaria, she and her child are at an increased risk for developing adverse health outcomes due to maternal fever, placental malaria which decreases nutrient flow to the fetus, and maternal anemia which has been associated with low birth weight (Uneke 2008). Studies have suggested that anywhere between 3 and 8% of infant mortality is due to maternal malaria, as infants of mothers with the disease are at an increased risk for neonatal mortality, premature labor, reduced fetal weight, placental infection and stillbirth (Haghdoost et al. 2007).

For countries throughout sub-Saharan Africa the economic and social burdens that malaria creates can be crippling. Such burdens include the need for large investments in medical care, as well experiencing sustained losses within the labor force (Sachs and Malaney 2002). A country's trade, tourism and foreign investments can be severely damaged by changes in economic behavior associated with high rates of the disease (Sachs and Malaney 2002). Families in disease-burdened countries tend to experience a reduction in savings, migration between malarious and non-malarious regions, as well as school attendance for children (Sachs and Malaney 2002). Many individuals and households will lose income (Sachs and Malaney 2002).

[1] Average rate increases in southern African countries, including Botswana, Zimbabwe, Swaziland, South Africa and Namibia were as high as a 28% for malaria incidence and a 114% for malaria-related deaths due to HIV (Korenromp et al. 2005).

These added stresses on society make it more difficult, yet all-the-more pressing, for countries to implement programs that will improve the public's health.

*Long-lasting Insecticide-treated Nets (LLINs)*

The introduction of insecticide-treated nets (ITNs) as a means of malaria control has been extremely successful in reducing incidence rates of the disease. The nets have been described as the "most powerful malaria control tool to be developed since the advent of indoor residual spraying (IRS) and chloroquine" (Hill et al. 2006). Studies on these treated nets have reported significant reductions in malaria-related deaths and malaria transmission. One study in Gambia, reported that an 86% bednet coverage reduced child-under-five malaria mortality rates by 63% (Aikins et al. 1994). Another study in Gambia reported at least a 50% reduction in the number of malaria cases for the general population after using bednets (Clarke et al. 2001).

More recently, the World Health Organization (WHO) has pushed for a switch from ITNs to long-lasting insecticide-treated nets (LLINs). These new nets are expected to retain their biological efficacy against mosquito vectors without retreatment for three to five years, while ITNs should be retreated with insecticide after three washes or at least once a year (WHO 2007). Both types of nets use pyrethroid insecticides, but the LLINs also contain an added binding agent that fixes the insecticide to the net material (WHO 2007). The use of these longer-lasting nets is not only cheaper in the long-term but reduces the need for reapplication of pesticides in the field (WHO 2007).

WHO is also making a move to scale up the distribution and use of LLINs within sub-Saharan Africa. In the past, efforts have been focused on distributing bednets to vulnerable subpopulations such as children under five and pregnant women (WHO 2007). However, with the nets' success WHO is now recommending full coverage of populations at risk to better protect the entire community (WHO 2007).

With more nets in use the hope is that there will be more extensive protection on both an individual user level and a community level. This community-level effect or "mass effect" exists because nets reduce the number of individuals in a community with malaria, and therefore decrease the probability of other individuals coming into contact with an infected mosquito (Teklehaimanot et al. 2007). Therefore the scaling up of net coverage will benefit people in the community who do not have or do not use bednets (Teklehaimanot et al. 2007). WHO is pleased with this approach to malaria prevention as it does not rely on the use of DDT and is therefore consistent with the priorities outlined by international conventions such as the Stockholm Convention on Persistent Organic Pollutants (Ministries of Health and of Environment of Madagascar 2008).

With an increase in LLIN distribution and use, however, come environmental and public health concerns. The sheer volume of nets put in circulation could contribute to litter and contamination throughout Africa. Areas with insufficient waste disposal, which is common in most of the developing world, are especially vulnerable to such problems (Njeru 2006). The nets themselves are made out of durable plastics that persist in the environment, and contain embedded pesticides (Ministries of Health 2008). The worry is that discarded nets will expose both the environment and human populations to harmful waste and chemicals. Up to 40% of the full beginning-of-life pesticide dose has been found in expired nets (Ministries of Health 2008). Additionally, nets often come in plastic packaging that could further exacerbate litter concerns.

Many African nations have already banned the use of polyethylene bags to reduce environmental impacts associated with flimsy grocery bags (CBC news 2007). More than being an eyesore, these bags have caused serious stormwater problems, blocking gutters and drains due to sheer mass (Njeru 2006). In cities like Nairobi, Kenya, plastic bags pose one of the biggest challenges to solid waste management in the city (Njeru 2006). The bags have been ingested by livestock causing serious health problems and in some cases death (Njeru 2006). Their persistence in agricultural fields has decreased soil productivity, and improper disposal of the bags has even been linked to the spread of malaria, by increasing breading habitat for mosquitoes (Njeru, 2006). Lastly, the bags, when burned release toxic gases including dioxin and furans in addition to leaving behind lead and cadmium (Njeru 2006). While all of these problems have not yet been linked to bednets, ITNs and LLINs contain the same amount of plastic polymer as 40 to 50 carrier plastic bags (Ministries of Health 2008). The 250 million new nets that WHO hopes to distribute by 2010 would translate into 1,000 metric tons of relatively homogenous plastic polymer (Ministries of Health 2008). Therefore investigation into end-of-life health and ecological implications for the nets should be a priority, as well as investigation into possibilities for take-back and disposal.

*Master's Project*

This master's project is being conducted for the United States Agency of International Development (USAID) Presidential Malaria Initiative (PMI) LLIN technical team. The team seeks guidance on the following two issues surrounding LLINs: 1) whether a disposal/recycling program is a possibility for manufacturers and donors, and 2) whether there are realistic possibilities for retrieving the nets after they have lost their efficacy.

The first issue deals with whether a bednet recycling program is a possibility for manufacturers and donors. Before nets can be collected, USAID wants to ensure that the nets have a place to go once taken from the field. Therefore it will need to be determined whether manufacturers are willing to accept old nets. USAID is also interested in knowing whether technology has been developed to recycle nets. If not, the LLIN technical team is interested in ways to encouraged manufacturers to develop such technologies. Cost will be another important factor for both manufacturers and donors. USAID would like to know if it is possible to internalize recollection and recycling costs so that they are incorporated into the initial cost of the net. An estimate for this cost will be requested from manufacturers.

The second issue deals how the nets should be retrieved after they lose their efficacy and no longer provide necessary mosquito protection. WHO estimates that bednets last from three to five years before this residual efficacy is lost (WHO 2007). However, even after nets have reached the end of their lifespan, they may retain some inherent value for beneficiaries. New and old nets alike have been used as fishing nets, drying cloths and wedding dress material by their users (Minakawa et al. 2008). Additionally, WHO would like to exchange an old net for a new net, but realizes that in some cases this may not be ethically possible (Beerbohm 8 Dec. 2008). This master's project addresses logistics and options for net recycling programs under these conditions. Already-successful programs in developing countries are examined, especially in areas where waste management infrastructure is lacking.

The overall objective for this master's project is to outline the main issues surrounding bednet distribution and disposal from the perspective of net manufacturers and distributors. It is also to elucidate all possibilities of further action for the PMI LLIN technical team at USAID as well as technical teams at Roll Back Malaria and WHO.

## Methods

Information for this project was collected though an extensive literature review and a series of interviews with net manufacturers and other stakeholders. The literature review collected details regarding LLIN use in sub-Saharan Africa, LLIN duration of efficacy and information on existing recollection and recycling programs in developing nations.

Interviews were conducted with manufacturers from late November 2008 to mid January 2009. To initiate communication an e-mail was sent to the following manufacturer contacts provided by Elissa Beerbohm with USAIDs PMI LLIN technical team: Thomas Sorensen (Vestergaard-Frandsen,) Rod Flinn (Clarke Mosquito Control,) Robin Slatter (Sumitomo Chemical,) Anuj Shah (A-Z Textile,) Robert Farlow (BASF.) The initiation letter introduced the interviewer and the project, as well as the type of information USAID was seeking. Interviews were conducted individually by phone with representatives from three of the five manufacturers who responded after sometimes multiple attempts to contact. For confidentiality purposes the names of representatives interviewed and companies are not used in this paper. These participants included Correspondent A (Public Health Area Manager at Company A,) Correspondent B (Director of International Business Development at Company B,) Correspondent C (Business Development Manager at Company C.) A sample of questions from the interviews is displayed in table 1.

| **Table 1. Sample manufacturer interview questions** | |
|---|---|
| **Background** | Into which countries are you currently importing nets? |
| | What individual packaging material do you use for your nets? What if any alternative/eco-friendly packaging has your company developed? |
| **Logistics** | Recently some African countries including South Africa and Rwanda have put restrictions on polyethylene groceries bags. Have these restrictions had any repercussions in the bednet industry? |
| | Would your company consider accepting worn-out nets? Is this logistically and economically feasible for you? Would your company be comfortable with an exchange policy where users return old worn-out nets for new ones? |
| | If costs were internalized about how much per net would the recollection and recycling process be? |
| **Disposal** | What are your current recommendations for how users should dispose of the nets safely? |
| | Has your company explored possibilities for recycling nets if they are recollected? |

Interviews were also conducted with Ralph Rack of John Snow Inc. and Stephanie Guillaneux of WHO Global Malaria Program. Both are doing work for their respective organizations on LLIN pull-back, and recycling and disposal, and they are collaborating closely with each other. In these interviews action that WHO and USAID might take to gain more insight into issues relating to bednet take-back and recycling was discussed, and valuable information about donor and in-country representative perspectives was obtained.

## Results and Observations

*Background*

As of January 2009, there were 2 LLINs approved by the WHO Pesticide Evaluation Scheme under full recommendation status: PermaNet 2.0 and Olyset Net (WHO 2009). PermaNet, made by Vestergaard-Frandsen SA, is a polyester net containing the pesticide deltamethrin (Zhuang et al. 2008). PermaNet fibers are surrounded in a pesticide-containing coating developed and patented by the company (Zhuang et al. 2008). The Olyset Net, made by Sumitomo Chemicals, is a polyethylene net containing permethrin pesticide (Zhaung et al. 2008). Permethrin is incorporated into the net fiber and through a process not clearly understood even by its developers, replacement pesticide migrates to the surface of the fiber to take the place of pesticide released (Hassan et al. 2008).

The Interceptor, Duranet, Netprotect and PermaNet 2.5 and 3.0 are all approved by the WHO Pesticide Evaluation Scheme under interim recommendation status (WHO 2009). The Interceptor, made by BASF in Germany, is the newest net to be approved by WHO (Zhaung et al. 2008). It is a polyester net which contains the pesticide cypermethrin (Zhaung et al. 2008). Duranet made by Clarke Mosquito Control contains the pesticide cypermethrin incorporated into polyethylene fibers (WHO 2009). Netprotect made by Intection is a polyethylene net with deltamethrin incorporated into its fibers (WHO 2009). Finally PermaNet 2.5 has a strengthened border around its deltamethrin-coated polyester fibers, and PermaNet 3.0 has both the strengthened border around a deltamethrin-coated polyester fibers and a deltamethrin and piperonyl butoxide (PBO)[2]-coated polyethylene roof (WHO 2009).

Pyrethroids are the only class of insecticide recommended by the WHO for use in ITNs and LLINs, at least in part because of their relatively low toxicity in humans compared to insects (Ehiri et al. 2009). Wide use of pyrethroids in treated nets began in the1980s after the development of more stable synthetic pyrethroids in the 1970s (Ehiri et al. 2009). Recently, there has been a growing concern over resistance to pyrethroids in mosquitoes and possible cross-resistance to organochlorine pesticides like DDT (Dabire et al. 2009). Table 2 shows WHO recommended doses for each of the currently used pesticides in bednets per square meter of netting. It also shows the acute toxicity data represented by dermal LD50s and chronic toxicity data represented by the no observable effect levels (NOAELs) in laboratory animals (Ehiri et al. 2009).

**Table 2. WHO recommended insecticide doses in mosquito nets used for malaria vector control and pesticide toxicity data in laboratory animals (Ehiri et al. 2009)**

| Insecticide | Dosage (mg of active ingredient per $m^2$ of netting) | Dermal LD50 (mg/kg/bw) | NOAEL (mg/kg bw/day) |
|---|---|---|---|
| **Alpha-cypermethrin** | 20-40 | 2,000 (10% Alpha-cypermethrin) | 1.5 |
| **Deltamethrin** | 15-25 | >10,000 (1% Deltamethrin) | 1 |
| **Permethrin** | 200-500 | 4,000-10,000 (10 Permethrin) | 5 |

[2] PBO is an inhibitor of microsomal mono-oxygenases, enzymes that catalyze the breakdown of almost all insecticides. It has been used extensively in conjunction with pyrethrins and pyrethroids specifically to preserve potency of the insecticides (Kumar et al. 2002).

Synthetic pyrethroids like deltamethrin, permethrin and cypermethrin were developed from the pyrethrin, an active principle in some Chrysanthemum flowers (Kreif et al. 2009). In general, pyrethroids very lipophilic and can readily pass through cell membranes (Ehiri et al. 2009). Their mechanism of toxicity involves binding to sodium ion channels in nerve cells, preventing them from closing and restoring sodium and potassium ion gradients across cell membranes (Krief et al. 2009). Pyrethroids may also alter calcium ion concentrations across nerve cell membranes by interacting with the GAMA receptor (Krief et al. 2009). In insects this leads to hyperexcitation of nerve cells, loss of coordination, tremors convulsions, dehydration and death (Kief et al. 2009). Appendix 1 shows the molecular structures of several pyrethroid molecules.

*Question 1) Is a disposal/recycling program a possibility for manufacturers and donors?*

The first stage of investigating possibilities for disposal or recycling programs into malaria prevention programs was to interview bednet manufacturers. Representatives from three of the five companies with bednets at various stages of WHO recommendation status responded and were available for interviews. All companies interviewed indicated that their nets were in circulation in most, if not all, sub-Saharan African countries sponsored by WHO and the Roll Back Malaria partnership (Correspondent A 9 Dec. 2008, Correspondent B 4 Dec. 2008, Correspondent C Nov. 2008).

Responses from each company regarding whether restrictions on polyethylene bags in some sub-Saharan African countries had created any problems for the bednet industry are outlined in Table 3.a. Overall restrictions did not seem to affect bednet distribution into any countries. While the representatives from two of the companies were at least familiar with such restrictions, correspondent C had not heard of them at all (Correspondent C Nov. 2008). He noted that his company not only distributes but also manufactures nets in one of the countries mentioned to have some of the strictest penalties for importing or selling polyethylnene bags less than 30 microns (Bengali 2006). Bags less than 30 microns are banned as thicker and stronger plastic bags are more durable and more easily recycled (Bahri 2005).

| **Table 3. a. Have restrictions on polyethylene bags in some sub-Saharan African countries created problems for the bednet industry?** | |
|---|---|
| **Company A** | Correspondent A was familiar with restrictions, but their companies had not experienced trouble importing nets in their plastic packaging. (Correspondent A 9 Dec. 2008) |
| **Company B** | Correspondent B somewhat familiar with restrictions. Added that bednets might be exempt because the more durable bednets lasted longer, while grocery bags were more for one-time-use and broke easily. Also he speculated governments would be more tolerant of bednets, because they are meant to save lives, than grocery bags. (Correspondent B 4 Dec. 2008) |
| **Company C** | Correspondent C had never heard of such restrictions. (Correspondent C Nov. 2008) |

When asked if companies would be willing to accept worn-out nets, all companies were enthusiastic and receptive to the idea, while some had already begun the process of working out logistics with WHO and other distributors. Table 3.b. outlines the companies' individual responses.

| **Table 3. b. Would your company be willing to accept worn-out nets? Is this logistically, economically feasible for you? What about an exchange policy for the nets, where users can return old worn-out nets for new ones?** | |
|---|---|
| **Company A** | Correspondent A stated that while the company would not be able to do the physical collection, her company would definitely look into recycling, and that this idea would certainly fall within company ideals for a sustainable brand. (Correspondent A 9 Dec. 2008) |
| **Company B** | Correspondent B gave a very enthusiastic yes to this question and mentioned that his company was currently working with WHO and other distributors to make this a reality. (Correspondent B 4 Dec. 2008) |
| **Company C** | Correspondent C stated that his company is currently working with WHO on a plan for disposal of their net, but that so far it is too |

| | |
|---|---|
| | early to say what they will decide on or even what all the possibilities are. However there is discussion about collecting the nets and having the manufacturers dispose of them and/or trading new nets for old nets. When asked if it would be economically feasible for his company to do this, He said that economics are less of an issue in these situations. The company is not looking to turn huge profits off of this, but that this kind of collection would have to be driven by aid support. (Correspondent C Nov. 2008) |

None of the companies had released recommendations with the nets detailing directions for safe disposal. Correspondent B noted that while his company had not released directions for disposal, neither had the net purchasers nor distributors. Furthermore, neither the net purchasers nor distributors had requested directions from manufacturers. However, two of the companies provided information about how they were trying to reduce waste in general (Correspondent A 9 Dec. 2009, Correspondent B 4 Dec. 2008). Table 3.c. outlines their individual comments.

| **Table 3. c. What are your current recommendations for how to dispose of nets safely?** | |
|---|---|
| **Company A** | Correspondent A said that there were currently no recommendations for disposing of nets after they have worn out. However her company was offering biodegradable bags for the nets for counties that requested them. She hadn't been on a job that dealt with these biodegradable bags, but knew Rwanda was one such country requesting them, and it may have something to do with Rwanda's ban on polyethylene bags. (Correspondent A 9 Dec. 2008) |
| **Company B** | Correspondent B said that there were no clear directions released for disposal, but pointed out that net purchasers and distributors were not providing direction either, nor are they asking the manufacturers for direction. He stated that his company is making a net that is stronger and has a longer lasting insecticide, as the insecticide is incorporated into the polyethylene instead of coated on the outside like most polyester nets. This reduces waste because fewer nets need to be distributed and in circulation. (Correspondent B 4 Dec. 2008) |
| **Company C** | Correspondent C stated that it was too early in the brainstorming process to tell. (Correspondent C Nov. 2008) |

In some of the interviews, conversation led to more discussion about what companies are currently doing to help reduce waste. Correspondent A, as stated above, had mentioned that her company is offering a biodegradable bag for its nets. She also mentioned that her company has thought about reducing waste associated with nets by packaging in bulk instead of wrapping each net individually. However, she pointed out that individual packaging seems to be the only way to ensure net instructions reach net beneficiaries at distribution. (Correspondent A 9 Dec. 2008)

Correspondent B also mentioned that his company was working on producing biodegradable packaging for its net. Additionally, he outlined technology barriers associated with recycling nets. He explained that while currently only a small percentage of the nets are recyclable, his company is in the process of developing an additive for their nets to make them 100% recyclable. Right now the biggest barrier is an inability to use enough of the worn-out net in making the new net without the material becoming brittle. The hope is that the new additive will help solve this problem so that more of the old net can be used in the new net or other recycled products. However, correspondent B noted that the additive will have to be developed for each net technology separately. In other words, the polyethylene net additive will have to be developed separately from polyester net additive. When asked which net type is more recyclable, he answered that right now the polyethylene nets were more recyclable, because the additive is being developed (Correspondent B 4 Dec. 2008). Mr. Rack from John Snow Inc. also indicated that because polyethylene can be melted down at a lower temperature than a polyester net, it can be recycled without vaporizing as much residual pyrethroid pesticide (Rack 16 Jan. 2009).

*Question 2) Are there realistic possibilities for retrieving bednets after loss of efficacy?*

For this question a literature review was conducted investigating re-collection and recycling programs in developing countries. This research gave a sense for which aspects of programs would fit best into retrieving bednets in sub-Saharan Africa. A summary of the various re-collection programs are outlined below for comparison in Table 4.

Table 4. Summary of re-collection and recycling programs in developing nations

| Program | Location | Description | Incentives | Success |
|---|---|---|---|---|
| **Collect-A-Can** | Main branch in **South Africa** with satellite branches in **Namibia** and **Botswana**. Also has representative offices in **Swaziland** and **Zimbabwe**. (Collect-A-Can 2009) | Joint venture between Nampak, the sole beverage can manufacturer in Sub-Saharan Africa, and Iscor to help collect beverage cans and scrap metal. Have partners in government, scrap metal industry and the beverage industry.<br><br>Has three main collector groups: scrap dealers, direct deliveries from outlying areas and independent collectors. Recollected has been assisted by volunteer collectors, companies, schools and charity groups among others.<br><br>Program encourages the recycling of used beverage cans through continued communication programs with the general public, education drives and on-going school competitions.<br><br>(Collect-A-Can 2009) | The program is subsidized by its shareholders, to create an incentive for people to collect cans. (Collect-A-Can 2009) | In its first year in 1994, program improved the recovery rate of cans from 18% to 25% in South Africa. The recovery rate is now 70% which is comparable with recovery rates in more developed nations. See Appendix 2. (Collect-A-Can 2009) |
| **Ecologia y Compromiso Empresatial (ECOCE)** | **Mexico** | ECOCE (Ecologia y Compromiso Empresatial) is a private initiative sponsored by bottlers and beverage producers. It was created to collect and recycle beverage containers. The organization has recognized that it will not be successful if they cannot change the mindset of consumers to recycle. Therefore large portions of the program's budget are focused on the promotion of recycling in schools. (Quinones 2003) | One of the main problems with recycling in Mexico was an inconsistent supply of recyclable materials. Because the price of the plastic fluctuates constantly so did the incentive to collect. ECOCE has focused on providing stable prices for PET to encourage regular collection. (Quinones 2003) | The program was collecting 23% of Mexico's PET bottles in 2003. However it faces the constant challenge of finding Mexican companies willing to buy the bottles to recycle and incorporate them into their goods. Currently 70% of material collected is sent to Asia. (Quinones 2003) |
| **Nokia phone and accessories recycling program** | Many African countries including **Nigeria, Ghana, Senegal, South Africa, Kenya, Uganda**, and **Tanzania**. (Nokia 2009) | Nokia recycling program in East Africa offers consumers a means of disposing old mobile phones and accessories. In the hope of encouraging safe disposal of these devices, consumers can drop their mobile phones off at designated Nokia centers and the company provides infrastructure to recycle them. (Nokia 2009) | No monetary incentive. (Nokia 2009) | Only 3% of people recycle phones in survey conducted by Nokia from 13 countries including Finland, Germany, Italy, Russia, Sweden, UK, United Arab Emirates, USA, Nigeria, India, China, Indonesia and Brazil. Nokia is working on raising awareness and |

| | | | | |
|---|---|---|---|---|
| | | | | expanding number of stores where take-back is an option. (Nokia 2009) |

Collect-A-Can is an organization headquartered in South Africa that promotes the collection of cans. It has satellite offices in Namibia and Botswana, and representative offices in Swaziland and Zimbabwe (Collect-A-Can 2009). It has had huge success in South Africa promoting the collection of cans in return for monetary incentives. It has improved the recovery rate of cans from 18% to 70% since the program's beginnings in 1994 (Collect-A-Can 2009). The now 70% recovery rate is comparable to some developed nations (Collect-A-Can 2009). In fact, Collect-A-Can has been such a successful model in southern Africa that a Collect-A-Bag initiative modeled after Collect-A-Can has been proposed in South Africa to alleviate waste management problems associated with plastic bags (Nhamo 2003). The majority of collection incentives are monetary with the highest prices awarded to deliveries made directly to collection centers, and deliveries of pre-cubed blocks of cans (Collect-A-Can 2009).

Collect-A-Can relies on a variety of collectors including scrap dealers, independent collectors, and volunteer collectors. Many of the independent collectors are unemployed and use can collecting as a principle source of income. Schools, companies and charity groups are among the volunteer collectors. Schools are of particular importance to the collection process, as they help educate future generations of recyclers. Many schools take part in collection competitions to encourage collection from household waste. Competitions include the Guinness World Record Competition where schools compete to beat the record for most cans collected in one month, the Poetry Competition where students submit writing samples on how recycling has improved the environment around the kids, and CAN CRAZE Competition where students can be creative and create almost anything out of cans. Recycling education is even incorporated into math curriculums at school with recovery trends displayed as graphs, etc. (Collect-A-Can 2009)

Ecologia y Compromiso Empresatial (ECOCE) is a PET bottle recovery program in Mexico, sponsored by the bottling and beverage industries (ECOCE 2009). In 2003 the program was recovering about 23% of PET bottles in Mexico (Quinones 2003). No other information regarding it success could be found. So far garbage separation in Mexican households is limited (Quinones 2003). To ensure long-term success the program has focused on changing the mindset of Mexicans so that they become more aware of recycling possibilities and incorporate separation of waste into their household routines (Quinones 2003).

In the short-term, however, the program has turned to "garbage pickers" who make a living selling trash from dumps in Mexico (Quinones 2003). The program has had to find ways to motivate garbage pickers to collect and return bottles consistently (Quinones 2003). Because collectors respond to the price of material, when the price of PET bottles fluctuates, ECOCE receives an inconsistent supply of materials (Quinones 2003). These fluctuations are one of the biggest challenges, and sometimes downfalls, of recycling programs (Quinones 2003). ECOCE's infrastructure was built in 1995 when price of PET bottles was $350 per ton; however, the program struggled in 1996 when the price dropped to $80 per ton (Quinones 2003). ECOCE has since worked on providing a consistent incentive for collectors to provide a more reliable source of bottles (Quinones 2003).

One concern worth mentioning within this system in Mexico is the presence of middlemen at dump sites. These middlemen organize groups of collectors who report to them with their bottles. The middlemen then return the materials to ECOCE after keeping a cut of the profit. They are very powerful and in some cases essentially control the dump. They often have the ability to refuse the entrance of the recycling trucks, forcing ECOCE to work through them.

The collectors who report to the middlemen sustain most of the risk involved in collecting bottles in sometimes toxic conditions within the dump. (Quinones 2003)

Nokia has created a take-back program in Nigeria, Ghana, Senegal, South Africa, Kenya, Uganda and Tanzania as concerns over electronic waste has increased (Nokia 2009). The company is providing infrastructure and directions for people to recycle phones and phone accessories at selected Nokia locations (Nokia 2009). However, the company does not provide any further incentive in the form of competition, prizes or monetary compensation (Nokia 2009).

The system is simple and low-cost, as it requires only moderate modification of existing Nokia infrastructure in these countries; however, a 2008 survey conducted by the company revealed that only 3% of people recycled cell phones in 13 countries including Finland, Germany, Italy, Russia, Sweden, UK, United Arab Emirates, USA, Nigeria, India, China, Indonesia and Brazil (Nokia 2009). The survey also reveled that a large part of the problem may be lack of awareness, especially in developing countries (Nokia 2009). Only 17% of people in India surveyed and only 29% of people in Indonesia knew that phones could be recycled, while 80% of people in the UK and 66% in Sweden and Finland were aware (Nokia 2009).

## Discussion and Conclusions

LLINs are designed to last for three to five years (WHO 2007). With PMI, an organization that has helped put millions of nets into distribution, entering its fourth year of operation, the volume of nets reaching their end-of-life stage in the near future will be massive. And, PMI is not the only organization contributing to net volume. Nothing But Nets, the Global Fund, and the Word Bank, just to name a few are also contributing organizations. Looking to the future, projections estimate that for 90% coverage of the 42 nations in sub-Saharan Africa, about 327.4 million LLINs will need to be distributed between 2008 and 2012 for campaigns covering children under

5 and pregnant women (Webster et al. 2008). For a universal access campaign, which WHO is now recommending, estimates increase to 545.3 million LLINs (Webster et al. 2008). The Roll Back Malaria program (RBM) hopes to have 250 million new nets in Africa by 2010 (Webster et al. 2008).

With many areas in developing countries lacking sufficient waste disposal, health and environmental effects of the plastic and residual pesticides in the nets is a concern. Immediate attention is needed for this issue to determine how the nets will be disposed of. The following paragraphs discuss the feasibility of take-back programs in sub-Saharan Africa, the recyclability of bednets, and the potential costs of such programs for manufacturers and donors.

*Take-back plausibility and logistics*

Today the United States, and a growing number of countries in Europe and East Asia, have begun imposing regulations on companies to provide incentives for product-take-back (Toffel 2004). These policies are meant to reduce both the environmental burden of the products as well as governments' municipal waste costs (Toffel 2004).

However, creating a successful take-back program in developing nations can be challenging, as a lack of sufficient waste management infrastructure and weak local authority may present obstacles (Korfmacher 1997). At the 2009 Alliance for Malaria Prevention Conference (AMP) in Geneva, Stephanie Guillaneux with WHO-GMP received mixed feedback over whether the nets could be recollected (Guillaneux 10 Feb. 2009). Participants at the conference included government, business, faith-based and humanitarian organizations (Roll Back Malaria 2009). Some institution representatives believed a take-back strategy would be feasible and necessary, while others believed it would very difficult given the lack of infrastructure and resources (Guillaneux 10 Feb. 2009). However, it was decided that before any further action could take place, additional research would need to be conducted (Guillaneux 13 March 2009).

To get a sense for the kind of program that would be appropriate for sub-Saharan Africa, a variety of take-back programs in developing countries were examined. Collects-A-Can in South Africa and other African countries; ECOCE in Mexico; and the Nokia cell phone program in various African countries seemed the most helpful in providing a variety of options with pertinent application for bednet take-back. Helpful aspects of the programs are discussed in the following paragraphs.

The Nokia program provides a low-cost example of a take-back program. It uses existing infrastructure such as Nokia stores to create a system where people are able to deposit their phones and accessories for recycling. However, while program provides instructions and means of recycling, it provides no further incentives. Existing infrastructure in sub-Saharan Africa such as bednet distribution centers, health centers and other community centers could be used in the same way for bednet recollection. Yet the low success rate of the Nokia program, with only 3% of people surveyed recycling their phones, highlights the need for modification.

All three programs addressed the importance of education and awareness to the long-term success of their programs. The Nokia program cited a lack of awareness that cell phones and accessories could be recycled as one of the main reasons for its low recovery rates (Nokia 2009). The Collects-A-Can program, which boasts the highest recovery rate of the three, relies heavily on education programs and competitions in schools (Collect-A-Can 2009). Although ECOCE relies on contributions from garbage pickers in the short-term they are investing heavily in education of children in order to both sustain and increase recovery of PET bottles from household waste in the long-term (Quinones 2003).

Additionally, ECOCE provides an insightful solution for programs trying to recover products in areas with little municipal waste infrastructure. Their incentives for garbage pickers to collect and return PET bottles from dumps and the streets transcends the need for a curb-side pickup system or even an immediate need for wide-spread household compliance with waste sorting. However ECOCE's experience does highlight the need for a consistent source of incentive to encourage a steady flow of materials (Quinones 2003). This is imperative as uncertainty on the supply side of product recovery is a common obstacle for manufacturers using recycled products even in developed countries (Thierry et al. 1995).

A program in Curitiba, Brazil has made use of a similar model, where residence of the developing community sell their waste for incentives like bus tickets, agricultural produce, dairy produce and children's school notebooks (Korfmacher 1997, Nath 1999). Although Curitiba is a sort of anomaly with its strong environmental awareness, this program called "Garbage Purchase" has been extremely successful and is credited with reducing litter and disease within the community in the absence of a formal garbage collection services (Korfmacher 1997). The program also provides an example of effective non-monetary incentives. Although it should be noted that non-monetary incentives like these will likely vary in effectiveness due to local values and preferences (Korfmacher 1997). For example, fishing communities around Lake Victoria in Kenya might prefer fishing nets to bus passes.

Regardless of the type and structure of the program however, studies in multiple countries have shown that recourse recovery programs have higher rates of success if they utilize existing collectors and infrastructure rather than attempting to create completely new systems (Korfmacher 1997). And in many developing countries there are already systems in place for such resource recovery, whether it be a formal waste management scheme with door-to-door collection, a scavenger and garbage pickers system, or a combination of the two (Korfmacher 1997).

USAID is searching for incentives like these that would encourage high returns of the bednets. Ideally, the LLIN technical team would like to create a take-back program where a new net is exchanged for an old net (Beerbohm 8 Dec. 2008). However, they realize that policies cannot be too strict, as they do not want to withhold nets from people who need them. It is likely that programs and incentives will need to be tailored to specific locations. For example, in areas where nets are free, incentives like bus tickets, agricultural produce, dairy produce and children's school notebooks might be successful as they were in the Curitiba, Brazil model. In areas where nets are distributed at low cost, free net vouchers with the return of an old net may suffice for incentives.

Anecdotal reports from the ground in Africa suggest local variation in willingness to forfeit old nets (Erskine 20 Dec. 2008, Smith 24 Dec 2008). Some villages have adopted unintended uses for the nets which are thought to contribute to the reluctance to give them up (Smith 24 Dec. 2008). Nets in Kenya around Lake Victoria have been used as fishing nets, drying cloths and wedding dress material (Minakawa et al. 2008). Anecdotal reports from a district in Burkina Faso state that stocks of nets are sometimes kept by villagers and nets are often used to wrap cadavers (Eriskine 5 March 2009). Marcy Eriskine from the Red Cross reported plans for a study in Burkina Faso in which reasons for withholding nests will be requested from households (Eriskine 5 March 2009). The study is planned to take place in April, May and June of 2009 (Eriskine 5 March 2009). Costs, benefits and the resulting necessary incentive will likely vary by country and region within countries; therefore more region-specific studies like this Burkina Faso project will be essential in decision-making efforts.

Currently WHO is supporting pilot projects being conducted in Madagascar, Tanzania and Kenya (Eriskine 5 March 2009). The projects are a part of a partnership of support between WHO, the United Nations Environmental Programme (UNEP), Strategic Management of International Chemicals Management (SAICM), NGOs, International Federation of Red Cross (IFRC), National Red Cross Societies, academia and the private sector (Ministries of Health, 2008).

The pilot project in Madagascar is already underway and will evaluate feasibility of a take-back program administered in conjunction with a distribution campaign, using both its infrastructure and personnel (Ministries of Health 2008). The main focus of the study will be on acceptability in the villages and environmental foot-print and cost-effectiveness. It will ask a range of questions on alternative uses for expired nets, ownership and uses of nets in the villages, and logistics and technical aspects of disposal and recycling including how these programs will fit into broader waste management practices in villages (Guillaneux 12 March 2009). More specific questions will address how to separate polyester and polyethylene nets, and how to improve awareness within the country for appropriate use and waste management of nets as well as to improve awareness of the social responsibility of industry (Ministries of Health 2008). An outline of the project steps, schedule and costs is located in Appendix 3.

*When are the nets expired?*

One of the biggest challenges is setting a standard for which nets can be recycled and when. Nets are made out of different materials and loses efficacy at different rates. PermaNet retains efficacy for about 20 washes after which it retains half of the original pesticide concentration (Zhuang et al. 2008). Olyset Net is reported to retain half of its original pesticide load for five years (Zhaung et al. 2008), although it is reported to maintain efficacy for up to seven (Malima 2008). The

Interceptor developed by BASF is the newest net to be approved by WHO (Zhuang et al. 2008). BASF has conducted an in-field test in India and concluded that the nets retain efficacy after 20 washings (BASF 2008), few studies if any outside studies have been conducted to confirm findings. Additionally variation in washing frequency from village to village or family to family will affect rate of efficacy lost.

Because of differences in net types, washing regimens and general use of nets, it will be very difficult to determine when a net has reached its end-of-life stage using time alone. However, new technology is being developed at the Center for Disease Control (CDC) that may help solve this problem. Steve Smith, a chemist at the CDC, has used a portable X-ray fluorescence analyzer that can measure insecticide content in bednets (CDC 2007). However useful this technology might be, it calls into question issues of cost and availability. Additionally it is only effective on one type of net made by one manufacturer (Rack 26 March 2009).

With no clear solution, manufacturers are likely going to have to deal with a range of concentrations coming back in used nets. As recycling technology develops it will be important for manufacturers to communicate how much pesticide their process can handle, as well as risks associated with evaporated pesticide to the environment and employees.

*How much will this cost?*

Although none of the net manufactures were able to provide an estimate for cost, the World Bank tentatively estimates a need for a 10% increase in net cost to cover take-back and recycling programs (Rack 16 Jan. 2009). Manufacturers did say that they were in the process of estimating costs, and therefore a follow-up with these companies is likely to provide a more accurate estimate. Regardless, Ms. Guillaneux at WHO confirms that donors would be willing to pay for such programs if they are deemed feasible and necessary to protect environmental and human health (Guillaneux 10 Feb. 2009).

*Environmental impact*

As WHO explores the logistics of disposal and recycling programs, it is also investigating whether such programs will benefit the environment in the long-run. In other words, what is the ecological impact of bednet disposal and recycling programs? From beginning to end, do total benefits outweigh the total costs to the environment?

To answer these questions a life cycle approach to program evaluation and development will need to be taken. There are currently a variety of systems analysis tools to assess impacts of industrial processes on the environment (Finnveden et al. 2000). However, the life cycle assessment (LCA) is most frequently used in the literature for environmental impact assessments, and it has been used to evaluate alternatives for municipal waste management (Woolridge et al. 2005). Developed in the 1990s, LCA is now a common tool used to evaluate environmental impact of products from "cradle to grave," although it does not include economic or social impacts (Finnveden et al. 2000). While a full LCA can be extremely involved and costly, the tool can also be used to assess specific lifecycle stages like the end-of-life stage, or a specific impact on the environment like energy or resource consumption (Woolridge et al. 2005).

There have been extensive LCAs already conducted on plastic waste steams (Finnveden et al. 2000). The general hierarchy established in one such LCA for PET bottles, specifically, prioritized actions for reducing environmental impact of waste (Finnveden et al. 2000). Reducing waste was most effective, followed by reusing, recycling, incinerating with heat recovery and finally using landfills (Finnveden et al. 2000). However, most LCAs, including this one, use conditions from developed countries, and are not applicable to sub-Saharan Africa.

To complete a unique LCA for sub-Saharan Africa, a common model to use is the Ecoindicator 99 (Huijbregts et al. 2008). It is available in SimaPro 4.0 software and a good resource to use for operation is Geodkoop and Spriensma (1999) (Finnveden et al. 2000). The model incorporates human health, ecosystem quality, extraction of resources and any additions to account for factors excluded from the general framework of the model (Finnveden et al. 2000).

*Alternatives*

As technology development allowed for the advent of the LLIN, further advances are now creating alternatives to plastic nets. A France-based company is developing a cotton net could be the next generation of bednets (Rack 26 March 2009). These more easily recycled cotton nets, could help alleviate concerns about waste disposal of plastics (Rack 26 March 2009). These nets are not a new idea, however, a newly developed technology that promotes longer pesticide efficacy in cotton, now allows them to compete with plastic LLINs in effectiveness (Rack 26 March 2009). While at the moment these nets are far from being in distribution, they provide possible solutions for the future. But before they are heralded as the answer to bednet waste management problems, comparison LCAs should be conducted to confirm their value over plastic nets from a cradle to grave approach.

*Conclusion*

Looking forward, take-back and recycling programs certainly seem like a possibility. Manufacturers are receptive to the idea of more environmentally friendly practices including recycling old nets and using biodegradable packaging. They are also continuing to develop technology to make recycling nets a possibility. Additionally, the World Bank's estimate for cost of recycling programs is feasible for donors at this time. Existing recycling programs in developing countries have also provided models of successful examples for take-back programs in sub-Saharan Africa. They highlight the importance of education and the value of using existing infrastructure for sustainable programs with high success rates. Pilot studies, some already underway, will provide essential information about logistics and environmental the impact of take-back programs. These studies may be able to provide helpful information to future LCAs, estimating the overall costs and benefits for people and the environment. With technology constantly changing, however, assessments may need to be conducted to compare costs and benefits of plastic nets to cotton nets. For now, stakeholders have agreed that bednets should not be pulled back until they have more information (Alliance for Malaria Prevention Conference 2009). To avoid duplicating efforts and to make best use of available resources, a better understanding of possible options for alternative uses, recycling or disposal are necessary (AMP 2009).

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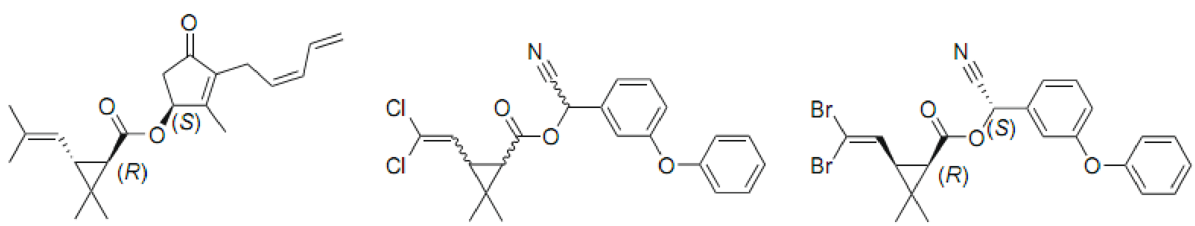
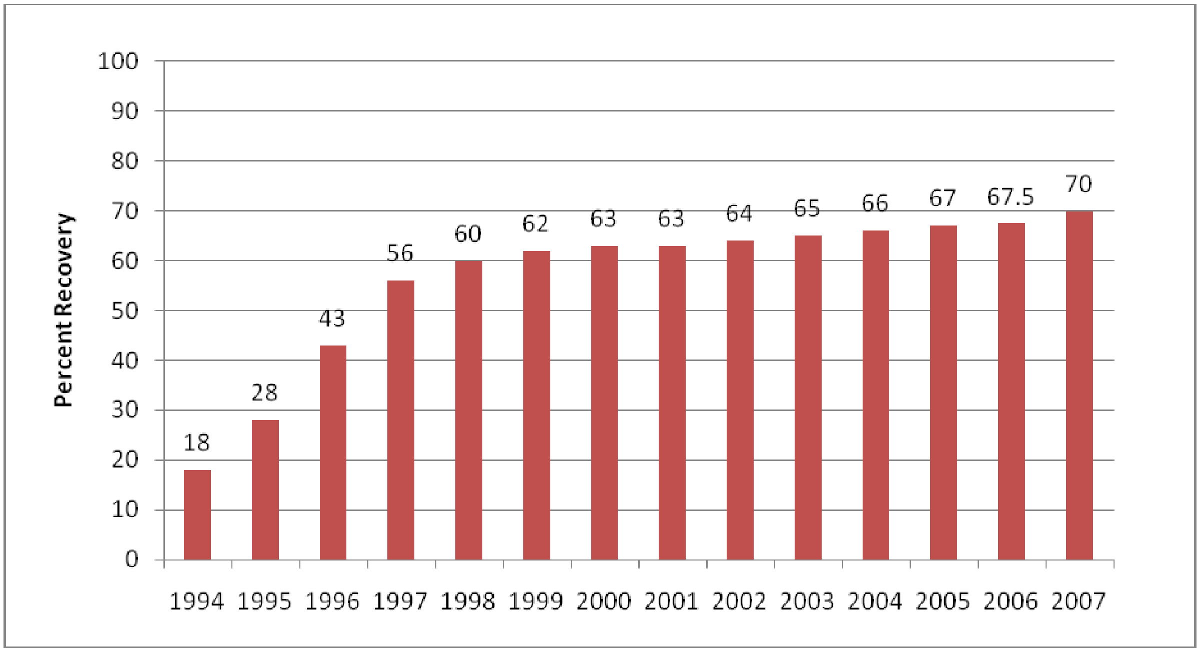
## Appendixes

Appendix 1. Molecular structure of pyrethroid chemicals (Krief et al. 2009)




**1a** Pyrethrin I    **1b** Cypermethrin    **1c** Deltamethrin

Appendix 2. Collect-A-Can Percent Recovery from 1994 to 2007 (Modified from Collect-A-Can 2009)




Appendix 3. Madagascar net pull-back project work plan (Ministries of Health 2008)

| ACTIVITIES | ACTIVITY DESCRIPTION | IMPLEMENTATION PERIOD | COST IN USD |
|---|---|---|---|
| **1). Publication of project brief on WHO/GMP and UNEP websites** | | **Jan. 09** | - |
| **2) Project Induction Meeting** | ***Brainstorming meeting of all interested parties and development of project roadmap*** (MOS, MOE Manufacturers, industries, partners( red cross, 5 Districts representatives)<br><br>***Meeting preparation***<br>- Elaboration of background documents and meeting presentations<br>- National travels and meeting participation<br>- International travels (3 persons: WHO, UNEP and research institute)<br>- Other meeting costs (administration, meeting room, etc.) | **Jan. 09** | **21,300**<br><br><br>1,500<br>3,000<br>15,000<br>1,800 |
| **3) Identification and testing of ITNs/LLINs collection strategies** | **Identification and testing of preferred options for the systematic collection of used nets**<br><br>***Initial visit to 5 selected districts*** (Manakara, Vatomandry, Ambanja, Marovoay and Amboasry Atsimo) including sites visits<br>- Transport (vehicle rent, fuel and maintenance)<br>- Perdiem (5x5 days for 4 people incl. driver)<br>- Site visits (5x1 day perdiem for 6 people plus local meeting costs)<br><br>***Visit to 5 districts during LLINs distribution campaign*** | **Feb. - Nov. 09** | **24,900**<br><br><br>5,900<br>3,900<br>2,100 |

| | | | |
|---|---|---|---|
| | *2 Back to back consultations to be held at district level (including local travels)*<br>- Discussion on collection strategies. Identification of best options for the systematic collection of nets taking into account the various distribution systems in place: mass distribution campaign, nets replacement campaigns, routine activity for vulnerable groups (pregnant women and U5s) at health facility level, strategy specific to remote areas (10%), and social marketing approach.<br>The recent « Programme d'action pour l'intégration des intrants de santé –PAIS (Drugs and Supplies Distribution Programme at National Level) » will be an opportunity.<br>- Discussion on recycling/disposal strategies. Technical discussion on destination of the nets collected and best logistics options. Feasibility for transport at district, regional level, national or international/regional level to be assessed looking into costs related to packaging and transport, infrastructures and transport capacities, international regulations for transportation of wastes, etc. | | 10,000<br><br>3,000 |
| **4) Support to chemical research institute** | **Research and testing of best technical options for the recycling and disposal of ITNs/LLINs**<br>- Research institute personnel and other costs related to project coordination and local execution<br>- Lab testing and recycling/disposal suitability studies<br>- Country/field visit (identification of potential facilities/infrastructures, contact with potential partners, etc.)<br>- Results evaluation, preparation of report/recommendations to be presented at the December meeting for result evaluation and proposal development<br>- Other costs (administration, communication, etc.) | **Feb. - Nov. 09** | **102,000**<br>36,500<br>54,000<br>6,500<br>4,000<br>1,000 |
| **5) Identification of countries and partners willing to participate into the large-scale proposal** | **Visits to potential partners:**<br>- Travels to at least 5 selected countries<br>- Visits to potential partners (e.g. WB, GFATM, UN Foundation, GEF, etc.) | **Apr. - Oct. 09** | **28,000**<br>20,000<br>8,000 |

| | | | |
|---|---|---|---|
| **6) Development of detailed project proposal based on result generated** | **Presentation of project results and project proposal development**<br>- Preparation project report and proposal development (consultant)<br>- Meeting on pilot project result evaluation and follow-on proposal development<br>- Elaboration of background documents and meeting presentations<br>- National travels and meeting participation<br>- International travels (3 persons: WHO, UNEP and research institute)<br>- Other meeting costs (administration, meeting room, etc.)<br>- Independent project monitoring | **Jan. 10** | **26,800**<br>4,000<br>1,500<br>2,000<br>15,000<br>1,800<br>2,500 |
| **7) Project management** | - Project management at national level (consultant)<br>- Project management and coordination at international level | **Jan.09 - Feb. 10** | **26,000**<br>6,000<br>20,000 |
| **8) Technical support** | In-kind contribution from partners on technical and coordination matters (staff cost) | **Jan.09 - Feb. 10** | - |
| **9) Other related costs** | Communication<br>Miscellaneous<br>In-kind contribution from partners on administrative matters | **Jan.09 - Feb. 10** | **13,500**<br>1,500<br>1,000<br>- |
| **10) Administration fees (8%)** | | | **18,500** |
| TOTAL | | | **250,000** |