USAID | DELIVER PROJECT

Madagascar: LLIN Recycling Pilot Project

Report on Phase III

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Madagascar: LLIN Recycling Pilot Project

Report on Phase III

USAID | DELIVER PROJECT, Task Order 7
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Abstract
In November 2010, the USAID | DELIVER PROJECT, Task Order 3, conducted an LLIN recycling pilot project in six districts in Madagascar. A total of 22,559 old nets were collected and subsequently shipped to the United States for testing and recycling by Trex, a plastics recycling company. This report details the results of Trex's initial recycling efforts, determines the viability (financial and otherwise) of recycling retired LLINs, and demonstrates the environmental benefits of recycling old LLINs.

Photo: Bales of old LLINs from Madagascar at Trex's facility in Winchester, Virginia. 2011. Photograph by Ralph Rack, USAID | DELIVER PROJECT

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Contents

Acronyms

BCC	behavior change communication
CDC	Centers for Disease Control and Prevention
CHW	community health workers
CLR	Consortium Lova/Réssources Vertes
CNC	National Coordination Committee
CS	collection site
FKT	fokontany
HDPE	high-density polyethylene
IEC	information, education, and communication
LLIN	long-lasting insecticide-treated bed net
MOH	Ministry of Health
NGO	non-governmental organization
NMCP	National Malaria Control Program
PET	polyester
PMI	The President's Malaria Initiative
PSI	Population Services International
QSP	Quick Start Programme
RFP	request for proposal
SAICM	Strategic Approach to International Chemicals Management
SDP	service delivery point
TOT	training of trainers
UNEP	United Nations Environment Programme
USAID	U.S. Agency for International Development
USG	United States Government
WHO	World Health Organization
WHOPES	WHO Pesticide Evaluation Scheme

Executive Summary

In November 2010, the USAID | DELIVER PROJECT conducted a first-of-its-kind recycling pilot project for long-lasting insecticide treated bed nets (LLINs) that had reached their end-of-life use in Madagascar. During the collection phase of the recycling pilot, which is described in detail in the precursor to this paper (*LLIN Recycling Pilot Project – Report on Phase II in Madagascar),* the project collected a total of 22,559 nets which were then shipped to the United States for testing by the World Health Organization (WHO)/UNEP (United Nations Environmental Programme) and by Trex – a private US-based plastics recycling company.

The project implemented an innovative public-private partnership with Trex - who was responsible for assessing the technical requirements for recycling the LLINs. The objectives were to develop practical recycling procedures for both polyester and polyethylene nets, and to determine if the nets could feasibly be recycled into bio-composite plastic-wood lumber to be used for decking. After the nets were collected, compacted and distributed to Port Dauphin in Madagascar by the project, Trex shipped the nets to the United States and conducted numerous tests on the nets before ultimately recycling some of the nets into a bio-composite plastic-wood board.

It was ascertained through the analyses conducted by Trex that polyethylene (PE) nets were able to be recycled but polyester (PET) nets were not. PET nets are more difficult to process, due to being multi-fibrous; this causes dirt and other contaminants to become lodged in the material. Additional testing on the PET nets is ongoing. PE nets have only a single fiber and require no additional preparation or washing before they are manufactured into a final product.

The exact age of an expired net remains inconclusive and is dependent on a number of factors. However, from the analyses conducted as part of this pilot project, it was discovered that the pesticide residue remaining in old LLINs (that are three years of age) can be quite significant. A number of the nets still retained a high enough degree of pesticide to provide a good level of mosquito repellence. Pesticide residue was also present in the densified form of the plastics from the LLINs, and may be found in the manufactured product (bio-composite plastic-wood board) as well. This may have implications for future uses of recycled plastics from old LLINs. Further testing is being conducted on the board to determine whether there is any pesticide rising to the surface of the board which may cause harm to humans or the environment.

While recycling retired LLINs is technologically feasible, it is cost prohibitive. Options to lower the costs of recycling must be explored if such a project is to become commercially viable. Some recommendations offered in the paper include: combining distribution and collection activities, requesting donors to cost share, or adding a fee to the cost of the final manufactured product that is divvied up by the manufacturers' market shares. While the costs of recycling are significant, this also must be weighed against the potential environmental benefits of developing a new recycling industry based on the management of retired nets.

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Introduction

By the end of 2010, approximately 380 million long-lasting insecticide-treated bed nets (LLINs) had been distributed in Africa as a result of global efforts to combat the spread of malaria (WHO 2010). LLINs are believed to have a lifespan of three to five years or twenty washes, and many of the nets in Africa – some of which have been distributed as early as 2004 – are now losing their efficacy. The continued presence of LLINs in communities as they approach or surpass retirement has numerous implications for the environment, as well as impacts on insecticide resistance (WHO 2010) and the uptake in usage of new nets.

In Madagascar, where more than 1.5 million nets were distributed during a mass distribution campaign in 2007, the Ministry of the Environment, Forestry and Tourism and the Ministry of Health expressed concern about the potentially negative environmental impacts resulting from the excess of retired nets. The Ministry of the Environment asked for assistance from the Quick Start Programme (QSP) trust fund of the Strategic Approach to International Chemicals Management (SAICM) to address this issue, and the USAID Mission also proposed that the USAID | DELIVER PROJECT be involved since its primary role in Madagascar under the President's Malaria Initiative (PMI) is to procure and distribute LLINs for future campaigns. Through a series of meetings in Antananarivo, it was decided that the SAICM QSP project and the USAID | DELIVER PROJECT would collaborate on a recycling pilot project – with WHO-QSP (the World Health Organization as the implementing partner for the QSP project) responsible for conducting an analysis of retired LLINs and the project responsible for exploring different options for collecting and recycling the retired LLINs.

During the first phase of the project, SAICM, the USAID | DELIVER PROJECT and NMCP (National Malaria Control Programme) assessed the feasibility of conducting a recycling pilot project in Madagascar. Once it was ascertained that critical infrastructure was in place, people were willing to return their old LLINs and that the pilot would in fact be feasible, the project moved forward with Phase II of the pilot. Phase II comprised of five steps: 1. Planning, design and development of the collection strategy; 2. Development and implementation of a communication strategy; 3. Site selection; 4. Contracting of vendors; and 5. Physical collection of the nets. The collection phase took place in November 2010 and a total of 22,559 nets were collected. The full details of Phases I and II are presented in the *LLIN Recycling Pilot Project – Report on Phase II in Madagascar*.

After the nets were collected, they were then shipped to the United States by Trex – a private U.S.-based plastics recycling company from Winchester, Virginia with whom the project developed a public-private partnership. The nets were then tested by WHO/UNEP (United Nations Environmental Programme) and by Trex. While the project's role in the pilot study was to determine the feasibility of environmentally-sound and cost-effective options for end-of-life management of LLINs recovered in Madagascar, Trex's role was to assess the technical requirements for recycling the LLINs into new manufactured goods. The purpose of this report is to present the results of Trex's initial recycling efforts, determine the viability (financial and otherwise) of recycling retired LLINs, and to demonstrate the environmental benefits of developing a new recycling industry based on the management of retired nets.

Considerations for Recycling Old LLINs

Supply-side Issues

A factor that strongly impacts the success of a collection campaign is the supply of old LLINs, i.e. how many LLINs are available for recycling. It can be challenging to determine the supply of old or retired LLINs in a country as there often remains a lack of agreement on what constitutes an expired LLIN (WHO 2011). As indicated in the *LLIN Recycling Pilot Project – Report on Phase II in Madagascar,* individual owner care and perceptions of whether a net is still considered useful are strong determinants of whether an LLIN is ready to be recycled. In addition there is a preference for repurposing the nets for alternative uses such as for fishing, a cover for crops, a shower curtain, a mattress cover etc. There is hope that the newly released WHO guidance (*Guidelines for Monitoring the Durability of Long-Lasting Insecticidal Mosquito Nets Under Operational Conditions*) will provide assistance to countries that are trying to determine when their nets are reaching the end of their useful life.

Even when there are millions of nets in circulation, the population may or may not be willing to give back their old nets. As discussed in the *LLIN Recycling Pilot Project – Report on Phase II in Madagascar*, there are a number of factors which impact people's willingness to give back their old nets such as: whether a household has enough nets to give back, whether a new net had already been received and installed in the household, and whether the net was purchased by the user or given to the household by a donor(in this particular case, the communities thought that all nets were from the Red Cross, who previously distributed nets). It is important to determine whether Malagasy would still value their nets in the same way if 1). they were to be informed of the benefits of returning their old LLIN(s) for recycling and 2). there were strategies in place to ensure a continuous supply of new nets to mitigate concerns regarding a lack of coverage for other family members if an old net was to be returned. More research needs to be conducted to determine the value (real or perceived) of old LLINs, and whether this factor impacts people's willingness to give them up for recycling efforts, as well as the correlation between the availability of new nets and the willingness to return old nets.

There are numerous considerations that impact the collection of old nets, such as the availability of nets currently in circulation, their age and their condition (i.e. specifically determining their readiness for retirement) – which is undoubtedly a challenge in many countries where there are rolling net distribution campaigns – and being able to separate retired nets from those that may still have one or two more years of use. If distribution and collection campaigns are implemented in conjunction, it will be necessary to consider the number of old nets that are still maintaining their efficacy to ensure that the number of new nets distributed is adequate to maintain appropriate levels of coverage.

Net type is also a factor in supply. For example, based on the analyses conducted on PE and PET nets that are described in detail in this report, it was found that PET nets cannot be recycled at this time, due to the increased amount of dirt and contaminants that become trapped in the fibers of the net as opposed to PE nets.

Finally, in rural settings, the cost of reverse logistics would potentially be more difficult and/or more expensive depending on accessibility to those sites (including the distance between sites, and prevalence of roads in the area). Such factors may increase transportation and other costs, may be more logistically complex and/or more time consuming. Increasing the number of retired nets that are given back may depend on combined distribution/collection efforts as well as increased behavior change communication/information, education and communication (BCC/IEC) dissemination efforts (*LLIN Recycling Pilot Project – Report on Phase II in Madagascar).*

Demand-side Issues

The value achieved for the plastic resin derived from old LLINs will establish an upper limit on the cost that can be incurred during net collection and re-processing if recycling is to be an economically self-supporting option for countries. This depends to a great extent on demand for the plastic from old LLINs, what products could be created from recycled plastic (i.e. if there would be a market for those products), and how acceptable it is in the end market to have recycled products that may still have pesticide contamination (it has not been determined at this time whether significant levels of pesticides still remain in a final product created from old LLINs)

When considering other successful waste collection activities in developing countries, waste streams are often combined which proves to be an effective way to recover material for recycling (Korfmacher 1997). However, it would be difficult to utilize this strategy for LLINs due to the possibility of contamination of other waste materials from the pesticides on the nets. Additionally, in the cases reviewed, the majority of success stories tend to be peri-urban (i.e. glass and paper collection), and/or focused on items with an inherent value such as mobile phones. This seems to reflect the idea that recycling is driven by economic fundamentals and that people are more inclined to go for the easiest markets first. Recycling programs that achieve high recovery rates also depend on supportive educational and promotional efforts, and on ensuring that a certain volume is maintained in order to sustain the operation. An example of such a program is ECOCE[1] in Mexico – a company that buys used plastics, sorts and bales them for resale to recycling plants. They set a minimum price per kilogram of plastic which ensures a steady supply to recyclers, and they also promote educational efforts in schools across the country and offer incentives to students for participating in the collection of plastic (specifically PET bottles).

The value of recycled plastic polymer is typically less than the value of virgin polymer, reflecting its more limited options for use. It is, however, possible for recycled plastic resin to have a higher value than that of comparable virgin polymer if there is 'added value' – i.e. through the demonstration of corporate social responsibility in which the consumer pays extra for the 'embedded' value of the final product (for example, tourist souvenirs). There are a number of enterprises around the world that sell crafts, souvenirs, and other items manufactured from recycled plastics. One example of a company that applies corporate social responsibility to the manufacturing of new products is Revolve[2] – a company based in the Philippines that produces sports apparel out of recycled PET bottles.

In the United States, the residential deck and railing industry is the largest market for the recycled products that Trex is able to produce (i.e. bio composite wood-plastic lumber). There are a growing number of reasons for the increased popularity of plastic lumber. For the consumer, there is a desire for a long lasting, low maintenance product that does not require sanding, painting or staining and is not prone to splintering, warping or rot. Additionally, the U.S. Environmental Protection Agency

[1] http://www.ecoce.org.mx

[2] http://revolve-phil.com/index.php

has placed a ban on the use of CCA (copper, chromium, arsenic) pressure-treated lumber materials. This has fueled the demand for alternative materials, with recycled plastic lumber moving to fill the market need. In Trex's case, since they use a combination of plastic and wood to create composite boards, old LLINs offer additional benefits because of the fact that the pesticides remaining in the material negate the need for additional chemicals to treat the final wood product.

Plastic lumber products are relatively new to the market, but there have already been enormous benefits to the U.S. and global economies (and the environment – see below). The estimate for the market size of plastic lumber and alternate plastic/wood composite building materials for the entire industry worldwide is $500 million. A market value of $2.60 per board foot is used as a bench mark price.

The future for products under development looks very bright. In addition to residential decking and railing, there are currently several structural grade plastic lumber products in development that would meet the civil engineering design requirements to carry the loads necessary to build structures such as pedestrian and heavy load bridges; joists, beams and girders for marine waterfront applications and break walls; pier pilings, railroad ties and many other applications where traditional materials are not holding up in outdoor applications or where harmful chemicals are being leached into the environment. Other products currently being made with composite wood include various types of outdoor furniture, garbage containers and park equipment.

If recycling operations were to be established in Africa – where a company is both collecting and recycling old LLINs – it is important to consider the market for the old LLINs in that context. For example, there would likely be little demand for decking or the other outdoor materials described above (as there is in the United States), but there would potentially be a demand for other types of building materials or for new LLINs that are recycled from old ones.

One example of a product currently under development that may be more suitable for an African market, is a child-friendly hygienic pit latrine. The latrine, which is being developed by Intelligent Insect Control, is actually a squatting plate that fits over the pit. By using a dry and wet seal, no visual contact to the pit is made, and it eliminates the intrusion of insects. It is also odorless due to the wet seal and can be flushed with as little as two liters of water. Where water is unavailable, a dry beak system can be used.

To make it easy to use, it has an elevated floor, a back wall, a space for a water bucket, and placement for an elevated seat (a removable high seat) for children, the elderly, the handicapped or pregnant women. The plate is cast in high density PE, and is easy to clean, minimizing the transmission of pathogens (IIC concept paper).

Environmental Issues

It is advisable that a lifecycle assessment of LLINs be completed in the near future to assess and compare alternative re-use, recycling or disposal options. This would be needed to determine whether, if taken holistically, the environmental costs to society of local disposal is out-weighed by the combined costs and benefits of take-back and recycling. There are a number of proprietary approaches to lifecycle assessments, some of which are required for various types of certifications such as Fair Trade. Throwing LLINs away or burning them has an environmental cost. There is also a potential environmental impact from using LLINs as fishing nets. For example, the small mesh size promotes the catching of juvenile fish and therefore can impact overall fish population recovery rates - possibly resulting in localized decline in fish stocks (WHO 2011). It is unknown how widespread and problematic these environmental costs or impacts are.

There are a number of environmental benefits that accrue from recycling plastics from old LLINs including:

- A reduction of solid waste materials in landfills.
- A reduction in harmful chemicals that may leach out of the nets and contaminate water or soil.
- A decrease in the usage of harmful chemicals (such as Chromium, Copper and Arsenic) needed to treat wood composite products, such as building materials, in countries in Africa where the use of CCA has not been banned.

1. Reduction in solid waste

According to a general analysis conducted by Trex, one board foot of composite wood weighs approximately 2.6 pounds and contains roughly 1.3 PE LLINs. Per cubic foot of recycled plastic lumber, there are eight PE nets. This means that for each board foot of composite wood that is created using recycled nets, 1.3 PE nets are diverted from a landfill.

Using one million board feet of bio-composite plastic lumber as a benchmark, Trex further determined that 1,300,000 PE nets, weighing a total of 1,298,000 lbs. or 650 tons, would occupy 800,000 cubic feet of space in a landfill. By instead recycling polyethylene from old nets, solid waste is reduced and is placed into long-term service as a durable product.

2. Reduction in possible risk of contamination of water or soil

There is no conclusive evidence that suggests that old LLINs that are disposed of improperly would contaminate soil or water (or create air pollution, if burned). However, we do extrapolate that there is a potential risk to the environment – based on the residue analyses completed by Intelligent Insect Control (refer to findings section) which indicate that there is still a significant level of pesticides remaining in nets that are several years old – i.e. these nets may still provide effective coverage from mosquitoes.

3. Reduction in usage of harmful chemicals used to treat wood

In order to treat lumber for utilization in outdoor purposes, such as decking, the chemical components of Chromium, Copper and Arsenic (a known carcinogen) are used. Approximately 0.4 pounds of CCA are impregnated into a cubic foot of material to treat the wood. There are other higher loadings utilized in the CCA industry (especially for marine utilization), but 0.4 is a commonly used value for residential applications and is selected for this comparison. If PE nets were to be used in composite lumber, there would no longer be a need to pressure treat the lumber since the contaminates in the polyethylene blend serve as fillers. This would be particularly beneficial in countries across Africa where there is no existing ban on the use of CCA. It may also reduce pollution in countries where pressure processing of lumber is common.

Other Considerations

An important consideration for recycling old LLINs is whether a country possesses the capacity to process the collected LLINs. In Madagascar where the pilot was conducted, the country did not have the necessary equipment to recycle the nets. Machinery (such as densifiers), as well as the trained staff required to run them, are an added cost. This may present a challenge for countries that prefer to recycle their old nets in-country, as opposed to shipping them to another country such as the United States or another country with recycling capacity and an acceptable regulatory foundation.

A final consideration is whether LLINs can be safely and legally recycled in a given country. The regulatory environment is often complex. Regulation applies to storing, shipping and recycling both plastics and, more importantly, plastics that have been in contact with pesticides (notably plastic pesticide containers). There seem to be a range of different schemes in different countries: some are mandatory and others voluntary.

In countries where it is proposed to establish an enterprise to recycle old LLINs, a review of the local regulatory environment will be necessary before an investment is made to ensure that the end product can be legally traded (if there is a desire to sell the end product to markets outside of that country) and what, if any, conditions will apply. Many African countries are in Free Trade Areas (FTA) and have the potential to sell recycled products to fellow FTA members. However, numerous countries have strict laws, to protect domestic industries, which prevent the import of recycled or used products. South Africa is a good example of a country that has a strict policy of preventing the importation of second-hand or recycled goods and has excluded these tariff lines from its FTAs in the region.

The safest approach is to maintain a chain of custody to ensure that plastic resin derived from used LLINs does not enter the general market and is used only in defined applications for which risk assessments have been undertaken – to ensure that any hazards associated with the potential presence of pesticides are managed to minimize potential risks.

Findings

There were three significant findings identified in the final phase of this pilot (Phase III):

1. **At this time, PE (polyethylene) nets are able to be recycled but PET (polyester) nets are not (see picture below).**

   Trex was able to feasibly manufacture the old PE nets into a final bio-composite plastic wood board. However, the PET nets were unable to be processed due to contaminants that were lodged in the fibers of the nets. Given Trex's current manufacturing process, they do not have the capacity to recycle PET nets at this time. Additional testing is ongoing.

On the left: bio-composite plastic wood board created out of recycled PE LLINs by Trex. On the right: recycled PET nets unable to be manufactured into a board.

2. **Recycling LLINs may reduce the amount of waste in landfills, may reduce the risk of water/soil contamination and air pollution, and may decrease dependency on the use of harmful chemicals to treat bio-composite plastic wood**

   As mentioned previously, there are a number of environmental benefits that may accrue from recycling old LLINs. The amount of waste in landfills may be reduced, because for each board foot of composite wood that is created using recycled nets, 1.3 PE nets are diverted from being sent to a landfill. Water and soil contamination, and air pollution may be reduced since recycling old LLINs will prevent them from leaching pesticides into the environment. Finally, dependency on the use of harmful chemicals to treat bio-composite wood may be reduced since the insecticide remaining in old LLINs serves as an effective substitute for CCA which has previously been used to pressure treat lumber.

3. It is not cost-effective at this time to recycle old PE LLINs

To determine the cost parameters for future take-back programs, the cost analysis is broken into two components – the cost of collection and the cost of recycling.

As discussed in the *LLIN Recycling Pilot Project – Report on Phase II in Madagascar*, it was determined that the cost per net for collection is $2.72 which is not inclusive of overhead costs. With overhead, the total collection cost is $5.44 per net. It should be noted that overhead is generally more expensive for pilot projects. The physical collection of the nets represents a significant portion of the total costs of the recycling pilot. Please see below.

Table 1. Total Collection Cost per LLIN

	Cost	Percentage of Overall Cost
Collection from sites, and transport to districts (CLR)	$1.19	44%
Transport from district to port, and compacting (Prorent)	$0.30	11%
IEC/BCC	$0.13	5%
Training costs (including awareness raising/consensus building)	$1.10	40%
Total cost per net	$2.72 *	100%

* The total collection cost per net is $5.44 if we account for both the cost of the activity and the overhead. Of the total cost of the pilot, 52 percent of that amount was the activity cost (as depicted in the table above) and 48 percent was the program cost.

The costs of recycling old nets will vary depending on the capacity of the company that recycles the old LLINs, as well the costs of required inputs versus the profit that can be accrued from the sale of the final product(s) made from the recycled nets.

One consideration for countries looking into recycling their old PE nets is that the plastic from these nets can be sold on the market, since high-density polyethylene (HDPE) is a high-grade plastic that is used by many manufacturers and recycling companies. The price for ground HDPE plastic, at the current market value is roughly $.50 per pound. The price for that same product with a contaminant (i.e. insecticide) is $.40 per pound.

Trex conducted a brief analysis to determine what the value added would be if one million board feet of plastic lumber (1,298,000 lbs.) comprised of 1,300,000 recycled PE nets were to be sold on the market at the value of .$40 per pound. It was determined that this quantity of PE nets would be equivalent to $519,000 (i.e. the market value of the plastic from recycled PE LLINs that would otherwise not exist if the nets were to be disposed of). See Table 2 below for further details.

Trex purchases plastic in addition to wood – at the cost of $.02 per square foot on the market – to produce bio-composite plastic wood decking. They typically manufacture composite wood from recycled polyethylene that comes from shopping bags and/or flexible packaging such as stretch wraps. There are a number of variables that determine the final price of the raw material that Trex obtains for its manufacturing operations, such as resin type, color, physical properties, cost and finally, the buyer/seller relationship. The highest price is obtained for raw material that is light in pigment since it can be used in many other color combinations for an end product. Old PE nets are a good source of plastic for the company since the pesticides remaining in the plastic negate the need for additional treatment of the wood. Barring the high costs of collection efforts, this could present an opportunity for further collaboration since the nets could be sold to Trex at the market value (minus $0.10 per pound due to contamination).

For companies in developing countries in Africa and elsewhere, purchasing old PE nets may not be feasible, but it may be possible to set up a looping system whereby old PE nets are collected and transported to a manufacturing facility in-country for recycling into new nets to be distributed in-country (an option could be A to Z Textile Mills Ltd. in Arusha, Tanzania).

Some factors that should be considered for local manufacturers who are interested in recycling old PE LLINs include: the cost of technology to separate the strings from the densified materials and to recycle the nets, and the electricity to run the machinery (depending on production this may run quite high; as an example, Trex keeps their operations running 24/7 since it is more cost-effective than shutting down and re-starting the machinery). If the nets are to be recycled in a developing country, it may be necessary to consider investments in technology and knowledge transfers, as well as building necessary infrastructure to support such an operation.

If the PE nets are unable to be recycled in-country, another consideration would be the shipping costs to send the old LLINs to the United States, Europe or another region where the nets could feasibly be recycled. Lastly, the end market for the product(s) created from the recycled material must be considered (some options are discussed in the section on demand-side issues). One of the greatest challenges is how to make a recycling program self-sustaining. At this time, net recycling is not cost-effective due to significant collection (and potentially other) costs.

Table 2. Added Value to the Market of One Million Board Feet of Plastic Lumber

Total Weight of One Million Board Feet of Plastic Lumber	Market Value	Total Value
1,298,000 lbs. of pure plastic	$.50	$649,000
1,298,000 lbs. of contaminated plastic	$.40	$519,000
Amount lost to value differences between pure and contaminated plastic: $130,000		

Trex Testing Results

Trex's role in the pilot was to develop practical recycling procedures for both polyester and polyethylene nets and to determine if the nets could feasibly be recycled into bio-composite plastic-wood lumber to be used for decking

The old LLINs that were collected by the project in Madagascar were received at the port in Baltimore, Maryland, USA, and transported to Winchester, Virginia by truck. The nets were unloaded from the truck and separated by plastic type. Samples were then sent to the Trex laboratory for testing. Using density surface chromatography, Trex tested the purity of the nets (to ensure that there were no contaminants in the nets such as other types of plastic). Testing protocol were completed to verify the level of the pesticides in the LLINs before processing, after processing and on the final recycled product.

The test results are as follows:

Table 3. Testing Results of Olyset (PE) Nets

Testing Results from Olyset Nets (PE)				
HDPE Nets	**Area Peak** [3]	**Melt Temp**[4]	**Onset Temp**[5]	**End Temp**
Group 1	123.5 °C	132.1 °C	123 °C	135.5 °C
Group 2	139.8 °C	135.6 °C	122.5 °C	140 °C
Group 3	141.4 °C	138.4 °C	126 °C	142.5 °C
Average	134.9 °C	135.4 °C	123.8 °C	139.3 °C

Table 4. Testing Results of Permanet (PET) Nets

Testing Results From Permanet PET Nets				
PET Nets	**Area Peak**	**Melt Temp**	**Onset Temp**	**End Temp**
Group 1	46.91 °C	256.2 °C	246.9 °C	262.9 °C
Group 2	41.14 °C	258.1 °C	247.4 °C	262.4 °C
Group 3	36.88 °C	258.5 °C	249.8 °C	263.8 °C

[3] The area peak is the total heat required to fully melt the sample. This is indicative of the density of the plastic. A higher area equals higher density.

[4] The melt temp is indicative of the "melting temperature" of the polymer. Polymers don't have a specific melting point, but instead melt or soften over a range of temperatures.

[5] The onset and end temps define the start and end to the softening process.

Table 5. Testing Results of Bale Sample of PE Nets Before and After Washing

Bale Sample Testing on Olyset Nets (PE) Before and After Washing				
HDPE Nets	**Area Peak**	**Melt Temp**	**Onset Temp**	**End Temp**
Group 1	113.5 °C	135.5 °C	122 °C	140.5 °C
Group 2	128.8 °C	134.9 °C	124.3 °C	139.1 °C
Group 3	113.3 °C	134 °C	121.8 °C	137.7 °C
Group 4 (Washed)	139.4 °C	134.8 °C	121.7 °C	140.3 °C
Average	123.8 °C	134.8 °C	122.5 °C	139.4 °C

Table 6. Testing Results of Densified Sample of PE Nets

Densified Sample Testing from the Olyset Nets (PE)				
HDPE Nets	**Area Peak**	**Melt Temp**	**Onset Temp**	**End Temp**
Group 1	139.4 °C	134.8 °C	121.7 °C	140.3 °C

Testing Methodology

The PE nets were densified using mechanical energy which created frictional heat to melt the nets. Temperatures of the material reached 126-138 degrees Fahrenheit. During the densification process, large amounts of polyester threading were extracted from the nets. Testing was performed on all stages of nets and it was shown that there are no significant differences in polymer[6] characteristics of nets through the entire cycle.

Findings

The PE nets were processed without complications and were ultimately able to be recycled into a bio-composite plastic-wood board. The board that Trex produced is composed of wood from recovered saw dust and waste plastics from the nets including high-density polyethylene (HDPE) and low-density polyethylene (LDPE). The powder or fibers were mixed to a dough-like consistency and then molded to the desired shape. Additives such as colorants, coupling agents, stabilizers, blowing agents, reinforcing agents, foaming agents, and lubricants helped to tailor the end product to the target area of application. The material can either be formed into both solid and hollow products or into injection-molded parts and products. For a picture of the final recycled material, please refer to page 7.

The densified sample testing of the PET nets is pending. The PET nets were 25% dirtier than the PE nets, and as a result, could not be processed. The first attempt to run the PET nets through a pelletizing[7] line failed. In this process, the net material goes into an extruder, then a screen changer and through a die head. The material is then water quenched and pelletized. During processing, the

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[6] A polymer is a long chain of similarly structured molecules (monomers).

[7] After a material is densified it is molded back together into a solid form, such as a pellet. Materials are typically made back into a composite so that they can be mixed with other materials, in this case wood.

net material went through the densifier and into the extruder, but could not get through the screen changer. The material backed out of the vent on the extruder barrel. Attempts to change the pressure or temperature led to the same results. The material also emitted a foul odor during processing.

Additional attempts to densify the PET nets are on-going. The contaminants are currently preventing processing, and further attempts are being made to process the nets after they are washed. A machine that burns materials at a higher temperature is needed. Processing temperatures for PE nets only need to go up to 93 degrees Celsius, whereas PET nets need to go up to 204 degrees Celsius. PET nets contain more porous fibers that cause contaminants to become lodged in between, as opposed to the PE nets which have a single fibrous strand. Unfortunately, the washing process is very costly and could present significant obstacles for future recycling of PET nets.

Trex staff members load nets onto the densifier


LLINs are densified at Trex's facility


Densified LLINs

NRI Testing Methodology & Results

After the retired nets were collected by the project in Madagascar, random samples of both Olyset (polyethylene) and Permanet (polyester) nets were sent to the Natural Resources Institute (NRI), who was asked by the World Health Organization (WHO) to lead the technical part of the pilot project research on feasible re-use, recycling, energy recovery and disposal options for LLINs. Within their role, NRI was asked to liaise with industry representatives to identity end-of-life use options for nets, in accordance with best environmental practices (BEP) and best available technologies (BAT). NRI identified Intelligent Insect Control (IIC) as a contractor for conducting a pesticide retention study on the old LLINs collected from Madagascar.

The analysis was conducted in IIC's Vietnam laboratory, and was intended not as an exhaustive study of nets in use as a malaria prevention strategy, but rather as an indicator of potential concerns if nets are employed for unintended uses or collected for disposal or recycling. The analysis was based on widely accepted methods used for determining rates of leaching – the release of insecticide over time – from the netting material, as well as from samples of products made from recycled LLINs, in this case a bio-composite plastic-wood board developed by Trex. While the methods used were not able to determine the cause(s) of insecticide loss, the analysis of the remaining active ingredient (insecticide used on the net) does indicate the range of losses – i.e. leaching rates – that occur from real world usage of nets.

Samples are cut from an old LLIN at Trex's facility

For the purposes of the analysis, twelve polyethylene (PE) nets and ten polyester (PET) nets were identified and segmented into samples, wrapped in foil paper, and shipped to IIC from the United States. Each numbered sample contained five 35 x 40 cm rectangles of netting: one from the roof and four from the walls. Upon receipt, the IIC laboratory cut $100mm^2$ circles from each panel to determine the current weight per m^2. A second set of square samples were carefully cut from the same netting, with the cutting instrument cleaned between net samples. The combined samples from the roof and side panels were then tested (Nguyen, 2011).

Dr. Olivier Pigeon, of the Walloon Agricultural Research Centre (CRAW) in Gembloux, Belgium confirmed that the method of analysis used by IIC on the nets was gas chromatography – a technique used to separate compounds. During this process, flame ionization detection was used in which the samples underwent chemical decomposition through intense heating from an air-hydrogen flame.

Olyset Nets – Testing Results

IIC utilized twelve Olyset nets and prepared samples for a weight and residue analysis. Each sample is labeled according to the net type (PE), the number (1-12), the district where it was collected in Madagascar, the manufacturing date, and lot number. The batch number was only available for one sample. The manufacturing date and lot number were illegible on two nets (#5 and #12) (Table 7).

The nets in this sample originally contained a 20g base of permethrin (+/- 3g/kg), based on a manufacturing date of 2007, which is the same year they were distributed in Madagascar (*LLIN Recycling Pilot Project – Report on Phase II in Madagascar*). IIC's analysis of the nets indicated that, on average, there is 10.7g/kg remaining on each sample, although there is significant variability, ranging from 1.37-16.78g/kg. Over 83% of the original manufacturer's weight was found in net #10 which was the newest of all the nets (manufacturing date of 2009). The net with the second largest amount of permethrin (net #6 with 16.09% remaining) was three years of age at the time of collection. The net with the lowest concentration of active ingredient (1.38%) was found to be on a net without a discernable manufacturer's date. There are six nets in this sample that contain 60% or more of the original pesticide, which indicates a strong level of mosquito repellence for these nets, according to IIC.

The analysis of the samples also indicated a cis-trans isomer[8] ratio of 50:50, with an outside limit of 30:70. This ratio is well within the manufacturer's specification across the entire range. This indicates relatively uniform isomer decay or leaching rates (Nguyen, 2011).

[8] An isomer is a molecule that is composed of two or more compounds with the same molecular formula but different molecular structures (arrangements of atoms in the molecule). Cis and trans isomers are molecules that each have a different configuration. The cis/trans isomer ratio is the percentage of each of the isomers that comprise the substance (i.e. permethrin). The variance in the ratio affects the toxicity of the pesticide. The average range, according to WHO is between 50:50 to 30:70.

Table 7. IIC Testing Results of PE Nets

Samples – Olyset LLINs	Weight (g/m^2)	Permethrin*		Trans-Isomer Ratio (%)**
		Content (g/kg)	Average (g/kg)	
PE-1/ Tsihombe/ Olyset/ MF date 063007/ Lot#23203960207	57.99	9.2653 9.3391	9.3022	59.05
PE-2/ Fort Dauphin/ Olyset/ MF date 063007/ Lot#123032040107	57.91	13.2580 13.2676	13.2628	57.75
PE-3/ Ampanihy/ Olyset/ MF date 063007/ Lot#132039060207	71.61	8.4934 8.4830	8.4882	59.81
PE-4/ Betioky/ Olyset/ MF date 063007/ Lot#132043060307	61.26	14.9005 14.9073	14.9039	58.51
PE-5/ Betioky/ A-Z Olyset net	46.84	12.5063 12.5274	12.5168	58.57
PE-6/ Betioky/ Olyset/ MF date 063007/ Lot#112005060307	57.71	16.0752 16.0983	16.0867	58.44
PE-7/ Ampanihy/ Olyset/ MF date 063007/ Lot#245056061607	64.45	8.7514 8.7218	8.7366	59.61
PE-8/ Ampanihy/ Olyset/ Lot#245054051507	60.11	13.7819 13.8196	13.8008	56.95
PE-9/ Betioky/ Olyset/ MF date 063007/ Lot#245048060307	72.22	5.4365 5.4308	5.4336	59.18
PE-10/ Ampanihy/ A-Z Olyset net/ MF date 100809/ Lot# 150223, Batch# 908	45.49	16.7937 16.7632	16.7784	58.17
PE-11/ Betioky/ Olyset	66.94	1.3686 1.3691	1.3688	62.08
PE-12/ Betioky/ Olyset/ MF date 063007/ Lot#145048060307	60.74	7.8738 7.8879	7.8808	59.99
Average Min/Max	60.27 45.29/72.22	10.7133 1.3688/16.7784		59.01 56.95/62.08

*Permethrin is a type of synthetic pyrethroid (insecticide) that PE nets are coated in.

**Trans-Isomers are a type of molecule. The trans-isomer ratio is the percentage of that molecule in the pesticide.

Permanet Nets – Testing Results

Ten Permanet LLINs, nearly all manufactured in 2007 were utilized in the weight and residue analysis. These samples were labeled in the same way as the Olyset LLINs, by net type (PET), number (1-10), the district where it was collected in Madagascar, the manufacturing date, and lot number.

For polyester nets, the original manufacturer's weight of 75 denier[9] nets is $30 g/m^2$. For 100 denier nets, it is $40\ g/m^2$. Assuming that the samples were 75 denier (which are the most common), the nets gained, on average, approximately 33% g/m^2. According to the chief analyst at IIC in Hanoi, it appears that all of the nets have accumulated dirt.

If the same assumption (of denier size) is applied to the consideration of pesticide content, the samples that once contained 1.8 g/kg of deltamethrin[10] now hold on average 0.41 g/kg . This represents a leachate loss of approximately 1.4 g/kg, or 78% from the original treatment. However, the data are widely variable. The range of residue detected was between zero to 0.98 g/kg. The highest level (.98 g/kg) indicates a retention rate of 54%, which would still provide good mosquito repellence, while the lowest concentrations of AI – found in at least six of the samples – would provide little or no protection whatsoever.

There appears to be little or no correlation between the remaining pesticide levels and the age of the nets. Both the Olyset and Permanet LLINs have residue levels that range from almost inert to biologically active. The relative weights are just as erratic as the concentration of active ingredient. It could not be determined what the contributing factors are to this variability (Nguyen 2011).

[9] Denier is a unit of measure of the mass density of fibers (for textiles).

[10] Deltamethrin is a type of synthetic pyrethroid (insecticide) that the PET nets are coated in.

Table 8. IIC Testing Results of PET Nets

Samples – Permanet LLINs	Weight (g/m^2)	Deltamethrin			Deltamethrin R-isomer		Deltamethrin R-isomer / Deltamethrin (%)
		Content (g/kg)	Average (g/kg)	Average (mg/m^2)	Content (g/kg)	Average (g/kg)	
PET-1/ Betioky/ Permanet/ MF date 0906/ Lot#12826	33.64	0.807 0.804	0.8054	27.094	0.0293 0.0290	0.0291	3.61
PET-2/ Ampanihy/ Permanet/ MF date 0906/ Lot#12826	34.57	0.2210 0.2203	0.2207	7.630	0.0101 0.0109	0.0105	4.75
PET-3/ Fort Dauphin/ Permanet/ MF date 0707/ Lot# 11547	46.50	0.9525 0.9587	0.9556	44.437	0.0459 0.0461	0.0460	4.81
PET-4/ Fort Dauphin/ Permanet/ MF date 0707/ Lot# 11547	49.91	0.1993 0.1965	0.1979	9.878	0.0075 0.0074	0.0075	3.79
PET-5/ Betioky/ Permanet/ MF date 0708/ Lot# 14638	41.76	0.3646 0.3654	0.3650	15.241	0.0092 0.0093	0.0093	2.53
PET-6/ Ampanihy/ Permanet/ MF date 0906/ Lot# 11336	35.438	0.1382 0.1367	0.1374	4.868	0.0076 0.0079	0.0077	5.62
PET-7/Ambovombe/Permanet/Super Moustiquaire/MF date 0804/ Lot# 10954	42.17	0.0428 0.0425	0.0426	1.796	No peak found	-	-
PET-8/ Betioky/ Permanet/ MF date 0907/ Lot# 12826	38.38	0.0140 0.0140	0.0140	0.537	No peak found	-	-
PET-9/ Fort Dauphin/ Permanet/ MF date 0906/ Lot# 12826	32.54	0.9742 0.9889	0.9815	31.942	0.0245 0.0238	0.0241	2.46
PET-10/ Beloha/ Permanet/ MF date 1006/ Lot# 11396	44.81	No peak found	- *	-	No peak found	-	-
Average	39.97		0.4133	15.936	0.0191		3.939
Min/Max	32.54/ 49.91		-/0.9815	-/44.437	-/ 0.0046		-/ 5.62

*No pesticide was remaining.

Washing Study

A supplemental washing study was conducted on the nets to determine whether dirt accounts for some or all of the variability in the data. A lack of soil on some nets may indicate frequent washing, although there is no conclusive evidence of this - and could also be a factor in the data variability. The same twelve Olyset and Permanet samples were utilized for the washing sample. The sample preparation and testing protocol consisted of the following steps:

- Condition the samples in ambient temperature for 24 hours;
- Use scissors to cut 15x15 cm samples for washing study;
- Desiccate the samples in a silica gel chamber for 12 hours;
- Weigh each subsample prior to wash procedure;
- Place each 15x15 cm subsample into a 1-L beaker containing homogeneous 500ml de-ionized water plus 0.2% soap (2g/l) solution;
- Place each beaker into a 30^{o} C water bath on a shaker table and agitate for 15 minutes at 155 movements/min;
- Each subsample is removed from the soap solution, rinsed twice in de-ionized water and agitated each time on the shaker table as above;
- Sub-samples are dried in the direct sun for 30 minutes;
- Sub-samples are placed into a universal oven and dried at 65^{0} C for 24 hours;
- Sub-samples are placed in the silica gel desiccation chamber for 12 hours at ambient temperatures;
- Each sub-sample is weighed. To determine the weight of dirt= weight before washing – weight after washing.[11]

There are several observations relevant to this study:

1. The amount of dirt or soil adhering to the nets after several years of service is significant.
2. There is 25% more dirt in the PET nets than the PE nets.
3. There appears to be little correlation between dirt levels and the active ingredient remaining, or leaching rates. Extensive washing may or may not be the source of variability in the level of pyrethroids remaining in the samples.

[11] All weights normalized to g/m^2

Table 9. Washing Study of PE and PET Nets

Samples: Olyset Permanet	Weight Before Wash (g)	Weight After Wash (g)	Weight of Dirt (g/m^2)	% Dirt	A.I. / kg	Weight g/ m2 After Wash
PE-1/ Tsihombe/ Olyset/ MF date 063007/ Lot#23203960207	2.8209	2.7905	0.6756	1.07767	9.3022	62.01
PE-2/ Fort Dauphin/ Olyset/ MF date 063007/ Lot#123032040107	2.9854	2.8719	2.5222	3.801836	13.2628	63.82
PE-3/ Ampanihy/ Olyset/ MF date 063007/ Lot#132039060207	3.0283	2.9616	1.4822	2.202556	8.4882	65.81
PE-4/ Betioky/ Olyset/ MF date 063007/ Lot#132043060307	2.7064	2.6795	0.5978	0.99394	14.9039	59.54
PE-5/ Betioky/ A-Z Olyset net	2.2004	2.1865	0.3089	0.631703	12.5168	48.59
PE-6/ Betioky/ Olyset/ MF date 063007/ Lot#112005060307	2.6572	2.6489	0.1844	0.312359	16.0867	58.86
PE-7/ Ampanihy/ Olyset/ MF date 063007/ Lot#245056061607	2.7577	2.7278	0.6644	1.084237	8.7366	60.62
PE-8/ Ampanihy/ Olyset/ Lot#245054051507	2.6845	2.6718	0.2822	0.473086	13.8008	59.37
PE-9/ Betioky/ Olyset/ MF date 063007/ Lot#245048060307	3.5525	3.4992	1.1844	1.500352	5.4336	77.76
PE-10/ Ampanihy/ A-Z Olyset net/ MF date 100809/ Lot# 150223, Batch# 908	2.1194	2.0582	1.3600	2.88761	16.7784	45.74
PE-11/ Betioky/ Olyset	3.1186	3.1022	0.3644	0.525877	1.3688	68.94
PE-12/ Betioky/ Olyset/ MF date 063007/ Lot#145048060307	2.694	2.6621	0.7089	1.184113	7.8808	59.16
PET-1/ Betioky/ Permanet/ MF date 0906/ Lot#12826	2.2339	2.2000	0.5022	1.517525	0.8054	32.59

Table 9. Washing Study of PE and PET Nets

Samples: Olyset Permanet	Weight Before Wash (g)	Weight After Wash (g)	Weight of Dirt (g/m^2)	% Dirt	A.I. / kg	Weight g/ m2 After Wash
PET-2/ Ampanihy/ Permanet/ MF date 0906/ Lot#12826	2.4132	2.3092	1.5407	4.30963	0.2207	34.21
PET-3/ Fort Dauphin/ Permanet/ MF date 0707/ Lot# 11547	3.2449	3.2162	0.4252	0.884465	0.9556	47.65
PET-4/ Fort Dauphin/ Permanet/ MF date 0707/ Lot# 11547	3.3934	3.1807	3.1511	6.26805	0.1979	47.12
PET-5/ Betioky/ Permanet/ MF date 0708/ Lot# 14638	2.9967	2.9213	1.1170	2.516101	0.365	43.28
PET-6/ Ampanihy/ Permanet/ MF date 0906/ Lot# 11336	2.3755	2.3426	0.4874	1.384972	0.1374	34.71
PET-7/ Ambovombe/ Permanet/ Super Moustiquaire/ MF date 0804/ Lot# 10954	2.9774	2.9404	0.5481	1.242695	0.0426	43.56
PET-8/ Betioky/ Permanet/ MF date 0907/ Lot# 12826	2.435	2.4207	0.2119	0.587269	0.014	35.86
PET-9/ Fort Dauphin/ Permanet/ MF date 0906/ Lot# 12826	2.2491	2.2261	0.3407	1.022631	0.9815	32.98
PET-10/ Beloha/ Permanet/ MF date 1006/ Lot# 11396	2.94	2.8799	0.8904	2.044218	-	42.67

Although the range of remaining pesticides is highly variable, there are at times significant levels remaining in the nets – even three to six years after manufacture (actual use could not be determined). These levels suggest that there are potential risks to aquatic species and other susceptible organisms (WHO 2011) in at least some instances when LLINs are used for unintended purposes (i.e. as fishing nets), or disposed of in the environment.

The residue levels that remain also indicate that protective measures should be utilized by persons that handle masses of nets in collection programs, or in confined spaces where recyclable resins are separated from dirt contaminants and are heated to melting temperatures. Additionally, it is likely that wash water and sediment from washing operations contain pyrethroid contaminants that may require appropriate environmental management.

Densification Analysis

A further study was conducted on the residue transfer of the nets in a densified[12] form to determine the level of pyrethroids remaining in post-consumer recycled products manufactured from LLINs. In this case, the bio-composite wood board produced by Trex, was shipped to IIC's Vietnam laboratory for testing on the level of pesticide leaching from the board and rising to its surface.

Methodology

The permethrin levels in the densified PE net samples were determined by capillary[13] gas chromatography and tested using flame ionization detection, with di-propyl phthalate[14] as an internal standard[15] (a control). The trans-isomer ratio was calculated from the chromatogram produced by the test. The concentration of permethrin is determined by the ratio of cis and trans-isomers.

Findings

The test results indicated that, on average, approximately 8.5 g/kg of permethrin remained in the densified PE net, with values ranging from 1.5g to 16g. It was determined that densifying the net material does not remove any significant amount of permethrin.

Samples were taken during the beginning, middle and end stages of the densification process, so this could partially explain the wide variance in values. Yet, the differences in values could have also been affected by variation in the content of nets. The concentration of Permethrin in the nets – i.e. values – was not obtained prior to their densification.

The temperature during densification was kept between 126-138 degrees Celsius, just below the destruction point, for a short period of time.

Final product testing on the pesticide residue of the recycled bio-composite plastic-wood board manufactured out of LLINs is still pending (Nguyen, 2011).

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[12]Densification is the process of compressing a material. By densifying the nets, it was shown that there were no other contaminants in the plastic.

[13] The capillary is a type of column or tube that the mixture of hydrogen-air passes through to heat the net - causing the pesticide to decompose.

[14] A phthalate is a chemical substance added to plastic to increase its durability and flexibility.

[15] An internal standard is a known amount of a compound that is added to an unknown analyte, or component. In chromatography, internal standards are used to determine the concentration of other analytes.

Table 10. IIC Densification Analysis of PE Nets

Sample Identification	Our ref	Test Method	Weight (g/m^2)	Permethrin		Trans- Isomer ratio (%)	Remarks
				Content (gr/kg)	Average (gr/kg)		
Densified PE net (Olyset)-Sample A	BU11-578/in1 BU11-578/in2	GC-FID CIPAC/4503/m PERMETHRIN (June 2006)	-	7.3919 7.3870	7.3895	58.28	
Densified PE net (Olyset)-Sample B	BU11-579/in1 BU11-579/in2		-	8.6737 8.6603	8.6670	58.59	
Densified PE net (Olyset)-Sample C	BU11-580/in1 BU11-580/in2		-	9.2422 9.3022	9.2722	58.50	

Conclusions

Through the Madagascar LLIN Recycling project, the USAID | DELIVER PROJECT implemented an innovative public-private partnership with Trex. The project took responsibility for collecting, compacting and transporting the old LLINs to Port Dauphin in Madagascar, and Trex took responsibility for covering the cost of shipping and testing the LLINs to determine the suitability of their use in new manufactured goods (i.e. a bio-composite plastic-wood board).

Trex has successfully demonstrated that old PE LLINs can be recycled and manufactured into bio-composite plastic-wood. This process demonstrated that composite wood manufacturing does not require clean plastic. Old nets can be extracted directly from the field with no additional processing or washing needed to manufacture them into composite wood.

At this point, it is not possible to recycle PET nets. Additional innovation is needed in order to make PET recycling possible. As indicated by the testing results from IIC, PET nets have shown to be a major challenge to recycle due to embedded dirt in the fiber. A dedicated washing procedure will have to be developed to remove the dirt, which will also increase the cost of recycling PET nets.

It was also shown through these analyses that pesticide retention is significantly higher on PE rather than PET nets. This is the result of fewer fibers in the PE nets, in combination with the method by which the insecticide is fixed on the fibers – i.e. embedded in the fiber versus adhered to the surface. Higher pesticide retention may also be affected by the age of the nets, how long each net has been used and the number of times it has been washed. Pesticide is also present in the densified material and may be in the manufactured product as well (testing is still ongoing to determine the level of pesticides remaining in the bio-composite plastic-wood board). This has implications for future uses of recycled plastics from old LLINs.

There are many potential commercial uses for plastic recovered from used PE LLINs – such as composite lumber used as building material for bridges, beams, waterfront break walls etc. – or to build child-friendly pit latrines or remake new LLINs. Much of this depends on supply and demand side issues – i.e. how many nets are available for recycling and what the end market is for products made from recycled nets. If sufficient material is available, an industry based on recovered LLINs is possible. Defined waste management scenarios, including potential recycling and recovery operations, provide pathways for controlled management of used LLINs.

The process of recycling nets currently remains cost prohibitive – with the major cost accruing from the collection process. It is likely that the cost of LLIN collection and pre-processing will remain greater than the financial value of the recovered LLIN. However, to increase the cost-effectiveness of a recycling program, the authors recommend:

- Combining distribution and collection efforts;
- Establishing an Environmental Investment Program (EIP) to help businesses capture the economic benefits associated with pollution prevention, waste reduction, re-use, recycling and sustainable products and process technologies;
- Adding a fee on the cost of the final product that is divvied up by the manufacturers' market shares;

- Establishing a revolving net fund for community health centers to take back old nets and give out new nets;
- Requesting donors to cost-share.

There is a need to further assess the potential savings that could accrue from these combined activities. International donors and relevant stakeholders should further explore cost-effective recycling options.

The ‘value proposition’ of recycled plastic lies within the raw material and finished products. Recycling old LLINs has a number of environmental benefits, including a reduction in solid wastes, a reduction in the leaching of harmful chemicals into the soil, water or air, and a reduction in the use of harmful chemicals to treat wood. NMCPs and donors need to determine whether the environmental benefits of recycling old LLINs outweigh the costs.

References

Intelligent Insect Control. 2011. *Concept for a hygienic latrine seen from a child perspective.*

Korfmacher, K. S. 1997. Solid Waste Collection in Developing Urban Areas of South Africa: An Overview and Case Study. *Waste Management and Research.* 15: 477–494.

Nguyen, H. 2011. *Test Report 2011-54/11CVN*. Intelligent Insect Control: Hanoi.

Nguyen, H. 2011. *Test Report 2011-53/IICVN*; Intelligent Insect Control: Hanoi.

Nguyen, H. 2011. *PE-PET Nets from JSI Chemical Retest after Washing*. Intelligent Insect Control: Hanoi.

World Health Organization. 2010. *World Malaria Report.* Geneva: World Health Organization Global Malaria Programme. www.who.int/malaria/world_malaria_report_2010/worldmalariareport2010.pdf

World Health Organization. 2011. Inception meeting for the pilot-study project on sustainable management of nets throughout their life-cycle, Geneva Switzerland, 10-12 August 2010 Report. http://whqlibdoc.who.int/hq/2011/WHO_HTM_GMP_2011_1_eng.pdf

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