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DESIGN CONSIDERATIONS FOR A SOLARTURTLE

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ABSTRACT

The SolarTurtle is a Spazashop style micro-utility unit designed for rural electrification in less-privileged communities of Sub-Saharan Africa. A standard 6m shipping container is converted into a theft resistant solar battery charging station business from which community members can buy a rechargeable battery pack. These battery packs are charged via solar power then carried home to where it can provide a versatile source of electricity. At night the solar panels fold away for security purposes, this is made possible by employing a unique ‘book-style’ mounting structure.

During the design process several design challenges had to be overcome in order for the SolarTurtle to survive South Africa’s harsh realities. Firstly, solar panels are often the target of theft and vandalism, therefore security measures must be in place. Secondly, maintenance in rural settings is difficult at best. The design must be robust enough to last as long as the solar PV panels. Thirdly if something should go wrong the broken components must be easy to replace, with minimal skills required. Hence a simple design is required without compromising the efficiency of the design. Lastly, the economic factor is of vital consideration. If the SolarTurtle is not economically viable the project will be unsuccessful. The previously mentioned challenges are only a portion of the design challenges that had to be met during the design process.

With a host of conflicting requirements a prototype SolarTurtle came to light. The prototype 3.6kW PV system powers a fleet of 300 battery packs and can serve households or businesses with basic electricity all year around. This paper will explore the journey taken to overcome some of the difficult design challenges faced in order to ultimately deliver a fully functional SolarTurtle prototype destined for the rural Eastern Cape of South Africa.

The SolarTurtle is a micro-utility that sells electricity to rural communities. It is a solar battery charging station (SBCS) fitted into a 6m shipping container and a solar panel security system. This women empowerment franchise business uses solar PV to recharge any battery off-grid communities might have - phones, tablets, car batteries, penlight batteries and bottled battery packs[1]. This enables woman entrepreneurs to sell electricity in any quantity require by turning all rechargeable batteries into solar power distribution devices. This enables the micro-utility to wirelessly reach numerous customers without relying on a grid connection. The challenge is to design the SolarTurtle in such a way that it is practical and affordable from an African perspective.

The design of the SolarTurtle has to consider many aspects. Some are considered more important than others, though none can be disregarded. To find an optimal balance between simplicity, security, robustness, scalability and numerous other considerations while keeping the final product affordable is the ultimate challenge. To do this a scoring matrix was devised against which several designs were rated. This rating process lead to the final design discussed in this paper. However, true to the iterative design methodology the new SolarTurtle design had to improve on the previous design as presented at SASEC 2014 [1]. For this we have to understand its shortcomings.

In the original SolarTurtle concept it was the responsibility of the turtlepreneur[2] to carry the solar panels from the container each morning and deploy them in the sun. In the evenings she had to reverse this process in order to lock the panels away in the container. This provided a cost effective solution for providing optimal security while still allowing the container to be transportable. However, there is a serious social risk. Deploying the panels in this way could lead to complacency, as it would require great dedication to deploy all the panels before the sun comes up and secure them after the sun goes down. First there is a risk of damaging the panels. Manhandling panels in and out of the container would surely lead to a breakage before the typical 20 year guarantee of the panel expires. Secondly the security advantage is only valid if the panels are packed away. However, the prototype is set to use around 4kW worth of PV capacity. This means either multiple panels, or larger and heavier panels are required. This risk of the panels

[1] Product of Khaya Power
[2] A woman entrepreneur in charge of the operations of the SolarTurtle

eventually just staying outside for convenience sake is too great. For these reasons an alternative solution was required. This led to the 'book-style' solar panel security system, which allows the panels to be packed away quickly and with minimal risk of manhandling.

The 'book-style' solar panel mounting concept is easy to use and fast to deploy. In the morning the turtlepreneur opens the gates attached to the north facing side of the container. Once the gates are open the panels hanging from the gate and the container is propped up with struts so that an optimal sun inclination angle is achieved. At night the panels fold down again by removing the struts and the gates close onto the container, sandwiching all the panels for safety. The gate locks securely on the inside of the container. Research shows this design is unique and offers the extra security needed without overburdening the turtlepreneurs.

This paper will explore the book-style design as well as various other possible designs considered for mounting the solar panels and how they were judged. Furthermore the interior design of the SolarTurtle will also be explored with special attention on security and safety. Finally the future of the SolarTurtle will be discussed. What other challenges are there still to overcome and how will these problems be tackled to deliver a fully functional micro-utility in a container.

BACKGROUND

Electricity is a commodity that is vital to modern living. Electricity provides a clean and safer light for a longer period of time, not to mention luxuries such as cellphones and TVs which are in high demand. However, Sub-Saharan Africa has a very limited grid supply leaving millions in the dark. In 2010 there were around 590 million people in sub-Saharan Africa without electricity (57% of the population). This statistic is expected to rise to around 630 million people by 2050 of which 70% is expected in rural areas [2]. The problem is further exacerbated by the on-going energy crisis. A cheap, fast and more accessible solution is required.

In 2012 the Cofimvaba Schools District Technology Project was lunched by the Department of Science and Technology (DST) minister, Derek Hanekom, in collaboration with the Department of Basic Education (DBE), and the Eastern Cape Department of Education. The project aims to improve rural education by exploiting the latest technological advances in education. Renewable energy naturally promotes this mandate, as it focuses on electricity – the most important component for ICT. Most modern technology relies on a readily available source of power and for this reason the Centre for Renewable and Sustainable Energy Studies (CRSES) at Stellenbosch University was approached for suggestions and the SBCS micro-utility model was proposed.

After several visits to the rural Eastern Cape and interviews with people living without electricity certain observations was made. Foremost the lack of security measures lead to rampant theft problems. In May 2013 a research team from Stellenbosch University were lead on a tour by the DST to four rural schools and one clinic who reportedly had solar PV solutions installed. The expedition team were eager to see solar PV solutions in action in a rural setting - unfortunately they never got to see any of these systems. Each location had the same story - A band of thieves arrived during the night and ransacked the PV systems installed on metal frames outside the buildings. The only exception was the clinic and this was only due to a 24 hour security guard. Though the raiders were chased off it was too late to save the system as it was already vandalised. Most of the DB wiring was pulled out leaving the system useless to the locals who did not know how to repair the damage. Another startling fact was that no one claimed ownership of the PV system as it was installed by an unknown government contractor. Hence the local institutions simply went without power as they had no one responsible to maintain or replace the systems. From these observations it became clear why ownership and security is so important for micro-utilities to be sustainable. This led to the initial design of the SolarTurtle with security in the form of a lockable steel container where everything could be stored. In addition the turtlepreneur takes ownership of maintenance and operations, as well as safety. However there are many secure solar panel mounting options available to consider.

EVALUATION MATRIX

Finding the optimal solution requires comparing all the options available on equal footing. For this a matrix of requirements along with accompanying weights were devised based on what is perceived as important to a good solar panel mounting structure.

1. **Cost** (10) – Since this is a rural community development initiative it is vital that the price remain minimal.
2. **Panel security** (9) – Ideally the panels should be locked away, preferably out of sight.
3. **Simple design** (9) – The simpler the design the more likely it is that the local community can maintain the system.
4. **Cable security** (8) – It is important to highlight the need to cable security. Both from theft as well as accidental short-circuits and fires.
5. **Simple installation procedure** (8) – With a simple deployment procedure less skilled labour would be required at the rural site. Ideally it should be possible to deliver the SolarTurtle with just a truck driver which would cut down on costs – Plug and play.
6. **Robust design** (8) – Maintenance in rural areas should be avoided. Prevention is better than cure.
7. **Scalable** (8) – The panel mounting solution must be expandable so more panels can be added if needed.
8. **Accessible** (7) - So women can operate, maintain and clean them.
9. **Fast deployment** (7) - The deployment of the panels must be no more than a minute per panel. If the packing of panels become a burden they might be left unsecure at night due to negligence.

10. **Safety** (7) - Each panel has a load on and can potentially electrocute the operator. Therefor safety measures must be in place to minimize the risk of bodily harm.
11. **Aesthetics** (6) – The Solar Turtle must appeal to both customers and investors. It is a business after all.
12. **Container transport** (6) - The frames will be shipped in/on the container. The mounting structure must fit inside for transport or adhere to transport regulations if fixed outside. They should be secure for transport.
13. **Sun tracking** (5) – It would be ideal if the operator can orientate the frames to face the sun to optimize production. However, direct angle manipulation should be minimized as it may lead to manhandling

Based on these requirements, 9 different solar panel mounting options were considered. The first options to be considered are the classical mounting options along with the original foldaway panel concept. This served as a bench mark for judging the rest of the designs. The rating of the concepts was carried out by a panel of judges who scored the various aspects with a rating out of 10. Totalling the results are converted to a percentage score which is used to rate the various designs.

Roof mounted slide out panels – Score 60.69%. The panels are all mounted on the roof. They are all stacked on top of one another and in the morning they slide out, exposing all the panels. Though this design is easy to transport it is not very cost effective and the robustness of the design is questionable. This design is also not very simple which means that the community would require help maintaining the system.

Classical ground mounting – Score 62.67%. In this classical mounting structure the panels are permanently mounted outside but secured to the frames fixed to the ground. This is a simple and a cost effective solution. However, this leaves the panels mounted outside at night, which poses a security risk.

Fold-away panels (Figure 1) – Score 63.27%. In the original design panels are secured to foldable frames and carried into the container every night. This design always had optimal security though the frames make the panel deployment heavy and unwieldy. Also building a frame for each panel is costly and time consuming. Human negligence is also a high risk.

Fixed ground mounted frames – Score 63.47%. The frames are fixed to the ground outside the container and the operator carries on the panels outside. Since only the panels are moved it is lighter load compared to the previous design. However, this requires permanently fixing the frames which is prohibits the SolarTurtle from easily being transported in the future.

Fold and twist design (Figure 4) – Score 64.06%. The panels are mounted onto the side of the container and locked into place. To open the panels they are unlocked twisted around then pushed to an optimal angle. Though the panels are left outside they are sandwiched between the container and the frames when locked allowing for extra security and also hiding the panels from view at night. However, this design is unique and requires complex engineering to construct which affects its simplicity and cost.

Side fold-out (Figure 5) – Score 65.74%. In this novel design the panels are mounted to two frames attached to the side of the container. In its secure position the panels are all sandwiched between the frames. To deploy the panels simply unlock the frame which then folds open. The two frames are then pushed up into the optimal angle. The drawback of this design is that the frames are unwieldy. Robustness of the design is also questionable.

Simple roof mounted (Figure 2**) –** Score 66.53%. Mounting all the panels on the roof is both simple and cost effective. By fixing beams to the roof the available mounting space can also be increased. The down fall of this design is security. The panels will be left outside and in plain sight. Also they are inaccessible, so the women would not be able to clean them easily.

Roof and side mounting (Figure 3) – Score 67.23%. This mounts two big frames to the side and the roof of the container. The frames fold down which allows the container to be transported. The downfall is still security. The panels cannot be removed from sight and can easily be reached from the ground. However, the angle of the panels can be adjusted to allow for better efficiency.

'Book-style' design (Figure 6-8) – Score 70.99%. Two gates are attached to the sides of the container. The panels are then mounted onto the side of the container and onto the gates with hinges. To deploy the panels the gates are unlocked from inside the container. The gates then swing open revealing all the panels. Gas struts lift the panels into the optimal angle which is adjustable. At night the panels are pushed down allowing the gates to swing close again and locked. This allows for fast deployment and minimal panel handling. The design is simple, secure, robust and still accessible to the operator for cleaning.

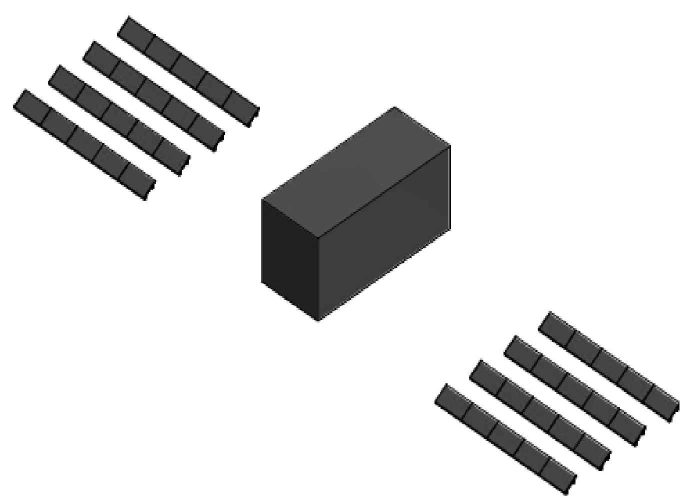

Figure 1: Original design with foldaway panels and frames

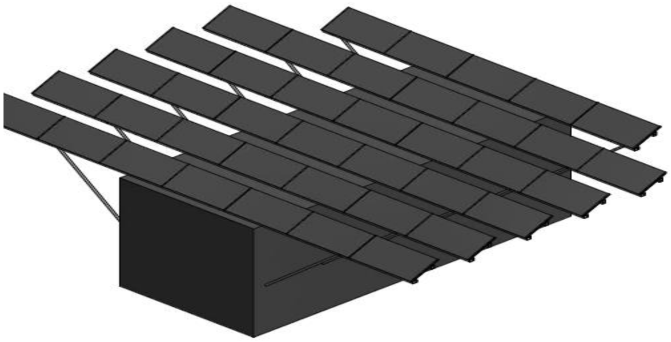

Figure 2: Simple roof mounted

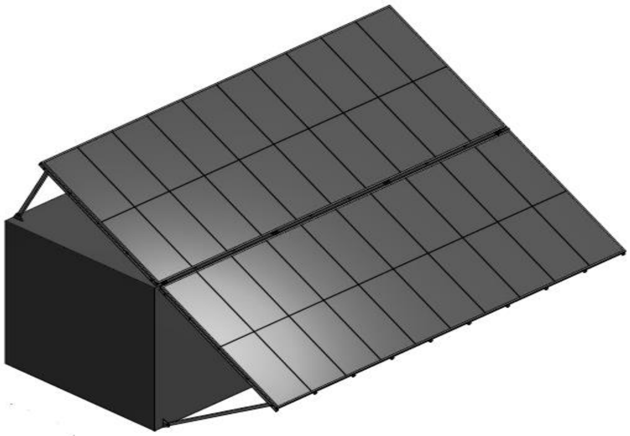

Figure 3: Roof and side mounting

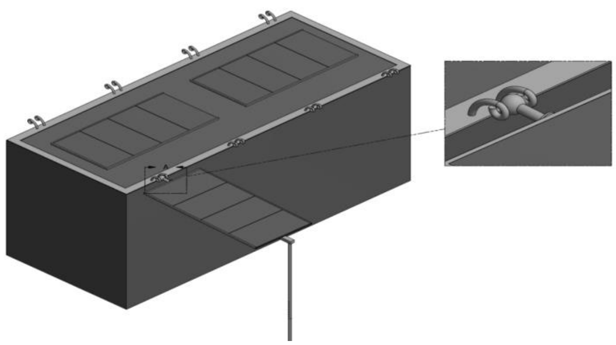

Figure 4: Fold and twist design

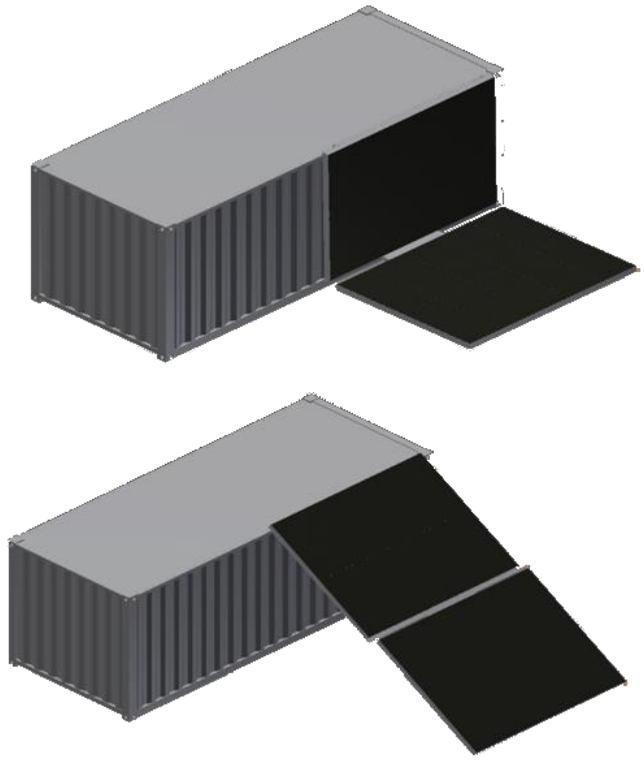

Figure 5: Side fold-out design allows all the panels to be packed away quickly but is still unwieldy to operate

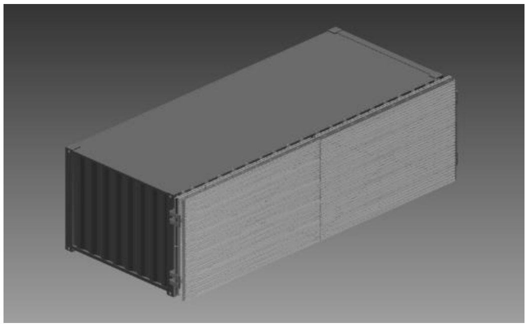

Figure 6: 'Book-style' - Solar panels are securely sandwiched between a steel gate and the container

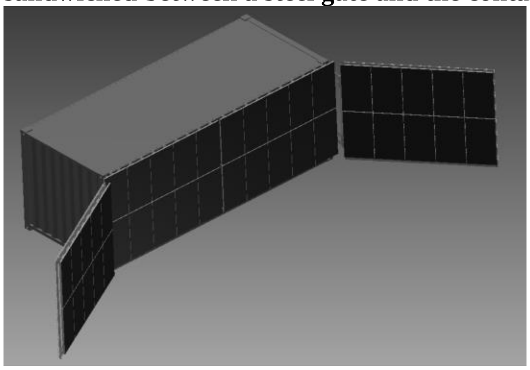

Figure 7: 'Book-style' - The security gates swing open revealing the solar panels

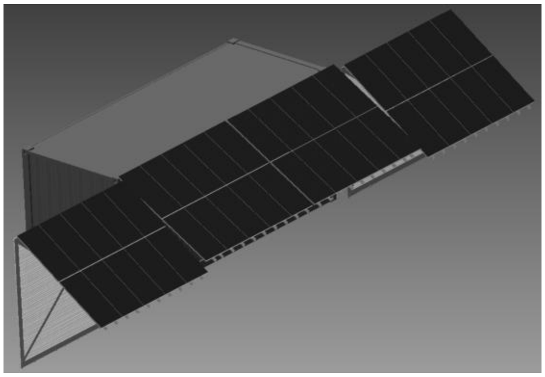

Figure 8: ‘Book-style’ - Struts are used to lift the solar panels to an optimal angle, based on the season

‘BOOK-STYLE’ DESIGN AND ANALYSIS

The main focus of the mechanical design work of the SolarTurtle related to the ‘book-style’ mounting and deployment of the system’s solar panels. As stated above, this system was chosen after applying an Evaluation Matrix.

The aforementioned design was made and analysed following these 3 steps:

1. Investigation of panel mount alternatives (including orientation solutions)
2. Design and failure analysis of gates to mount panels
3. Design and failure analysis of hinges

These steps were not necessarily followed chronologically, however, but rather were applied in an iterative process. The final design of SolarTurtle (at this stage) was made by attempting to ensure simplicity, cost effectiveness and robustness, as stated above, while making use of readily available solutions wherever possible. Particular attention was paid to minimising the closed width of the system for transportation considerations.

The method of mounting the solar panels was the first part of the design to gain advantage by considering the use of existing products. Since solar panels are used extensively in the mounted-perpendicular-to-the-sun’s-incident-rays fashion applicable to our design, it was decided to make use of hinged steel tubes onto which the panels are affixed.

Initially varying orientations were also part of the investigation scope of this design but it was decided to focus on 33°, which represents the best year-round declination. This single angle can be readily achieved with steel tubes of a single length appropriately attached to the tubes mentioned above. Thus a simple and robust overall panel mount design was chosen after considering U-Channel beams and telescopic or hydraulic struts, respectively, for example.

The design and evaluation of the gates, intended to actuate the ‘book-style’ variant of the SolarTurtle was obviously of critical importance. Such an analysis was made to ensure minimum cost while maintaining simplicity and robustness.

Iterations of this element were designed and tested using CAD software from a plate steel bolted assembly to the 2mm to 4mm thick steel tube welded design found appropriate to support the solar panels and minimise deformation. The gravitational load was considered along with a wind load representative of high wind velocities.

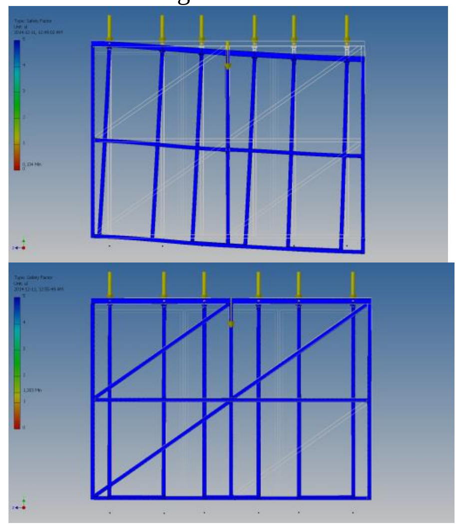

Figure 9: FEM analysis used to optimise the gate design

The next stage in this design and evaluation was to design the hinge element for the SolarTurtle. A hinge arm was required to place the gate’s hinge away from the container. This became a significant part of the design. Initially a bent steel plate with pin-barrel hinges was considered but was expected to experience substantial deformation under load. Even supporting the arm with a welded rib did not prove acceptable.

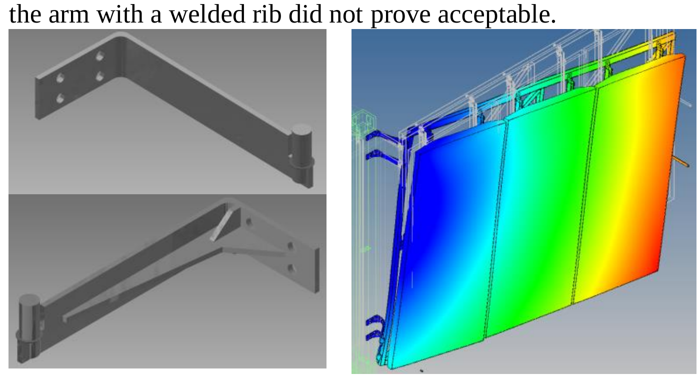

Figure 10: The first hinge designs warped badly

In the end it was decided to use a welded steel tube hinge arm along with a simple bracket-bolt hinge. The addition of a separate support (and wind stop) to the system, mounted to lock the gate in place but also take its weight off the hinge arms also ensured minimum risk of failure.

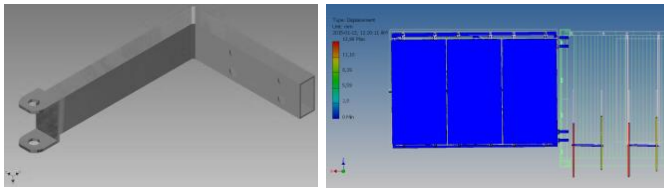

Figure 11: Rectangular tube hinge design FEM

The final design allows the SolarTurtle operator to deploy the 12 Yingli panels and lock the system with minimum effort by maintaining simplicity and robustness after much iteration and deliberation. The system is also capable of closing and locking up to ensure protection of the power generators.

CONCLUSION

The main focus of the SolarTurtle was on designing a system that is suitable for Africa. It has to be simple, robust, secure and cost effective but without making it difficult to operate and maintain. The new SolarTurtle design does exactly that. The novel book-style panel mounding design allows the operator to deploy the solar panels quickly and with minimal risk to the panels or personal safety. Furthermore the design can still be transported without removing the panels. This allows the SolarTurtle to be fully assembled off-site and transported to where it is needed. Once at the site the truck driver can unload the container then depart. No onsite labour is required.

The SolarTurtle has also been designed for rapid assembling and requires minimal skills. Extra attention has been given to security as this is a women empowerment business and they should feel safe operating the business. Steel gates provide security during the day and at night the whole container folds up and locks away. Just like a turtle – during the day it eats and at night it retracts into the safety of its shell.

With a simple and effective design the SolarTurtle can make a tangible difference to the lives of those who life in remote off-grid locations. The business can be operated with minimal skills or knowhow and can start trading the same day it arrives on site. The design is also robust enough to survive Africa’s harsh realities. Solar panels are typically guaranteed for around 20 years and with this design the SolarTurtle might actually survive long enough to see the warranty expire. The aim is to have SolarTurtles all across Sub-Saharan Africa allowing women at the grass-root level to tap into the potential that renewable energy to secure a better living for themselves and their communities. The next phase is to test the design in a practical setting in the rural Eastern Cape which would commence early 2015. If all goes according to plan the first SolarTurtle might actually start producing and selling electricity for a profit – Giving the power back to the people.

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