MECS Technology Research Innovation for International Development (TRIID) Project Reviews – Energy Storage

Picture Credit: AMPERES/Switch Batteries/REAM

Modern Energy Cooking Services (MECS) Programme

January 2021

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This material has been funded by UKAid from the UK government; however, the views expressed do not necessarily reflect the UK government's official policies.

Executive Summary

This report sets out to review the learning from the first Modern Energy Cooking Services (MECS) Challenge Fund programme which addressed energy storage as a part of the provision of modern energy cooking services (mecs) in Foreign and Commonwealth Development Office (FCDO) priority countries in sub-Saharan Africa and Asia. It constitutes one of four reviews which address the research themes for the TRIID call.

This review focuses on four projects spanning Myanmar, Ghana, Kenya and Uganda and Tanzania; it considers how to provide energy storage as part of a locally produced, low-cost cooking solution for rural and urban users.

The research offers great insights into the state of current technology and potential for development in the near future, drawing attention to issues associated with supply chains, effective storage methods, insulation and cooking culture.

In Myanmar, attempts to address the local shortage of energy by re-purposing waste lithium ion batteries were undertaken. The remaining other three projects, based in African countries, reviewed the use of phase change/thermochemical storage solutions. Two of the projects which relied on storing the phase change for a period of time, found that insulation was a key issue, while the third piloted an innovative solution that didn't rely on insulation, but encountered issues with the cyclability of the storage material and a low energy efficiency.

The potential for phase change materials offer a significant benefit, theoretically. At the current time, the issue is to turn this theoretical benefit into a reality. For this reason, each project requires further work to address the issues that they raised

However, all the projects offered considerable learning and insight into the potential for energy storage solutions, offering suggestions for the way forward to enable benefits from these alternative sources. Whilst further research is required to deliver a system that can provide for the needs of the average family, it is encouraging to note that similar issues are increasingly raised across the projects (the role of insulation, supply chains, transparent information) which offer a focus for further work to help smooth the way once the technical difficulties are overcome.

Challenge Fund Overview

MECS-TRIID Challenge Fund was run to support innovative cooking projects with a four-fold approach:

- Reduce barriers to innovation and advance technology in modern energy cooking.
- Enable a more sustainable, economical, and easily accessible cooking system in countries supported by FCDO.
- Develop smart ideas that have the potential to advance further.
- Fund early-stage innovations to take to the next stage of development.

The call focused on four themes that would address some of these issues:

Energy storage for cooking - Stimulate ideas generation and test initial concepts around how energy storage could be used in transitions towards the use of modern energy cooking services in one or more countries supported by FCDO.

Grid and infrastructure adaptability - Ideas for new solutions and approaches which help to improve the transition to MECS by improving grid (both national and localised grids) infrastructure were sought. This also includes work to assess challenges of getting the grid to reach all households and enabling consumers to connect to the grid.

Alternative fuels - research into developing new solutions and approaches that improve the implementation and adoption of modern energy cooking services based on fuels other than electricity and provide tangible benefits.

Delivery models, Gender, Accessibility (vulnerable groups such as people with disabilities) and inclusion in MECS - research into developing new services, solutions, and approaches which can demonstrate how modern energy cooking services can be made equitable for men and women, people of different social groups and people with different physical, sensory or cognitive impairments or mental health issues and which will provide tangible benefits and impact.

Applications were varied across the themes but generated a large number for delivery models and alternative fuels.

Energy Storage Theme

There are emerging possibilities for enhancing the transition of African and Asian economies to modern energy cooking services, by the inclusion of energy storage. To date, research has focused on the potential for utilising Lead Acid, Lithium Ion Phosphate and Saltwater chemistries in batteries. While Lead Acid seems to have limited application, the ongoing price falls of Lithium based batteries driven by the learnings from manufacture in the electronic industry, electric vehicles and larger and domestic scale energy storage, suggests that Lithium based batteries may be, for the near future, the ‘chemistry of choice’. Salt water and Nickel Iron batteries also hold some promise. There has also been limited research on Phase Change materials as a mechanism for matching cooking demand with energy supply. While thermal based solutions are in scope, we note that culturally the aspirational nature of electricity will likely lead to stronger consumer acceptance of chemical batteries over phase change alternatives. However, to date, research has been limited.

Company	Project Title	Project Area/Country	Main Focus
AMPERES	e-waste to e-cook	Myanmar	The project employs an accelerated prototyping approach to demonstrate the viability of recycled lithium ion batteries as an affordable, reliable, clean, and flexible power source for e-cooking in remote households of Myanmar.
CalPoly	Thermal Storage with Phase Change Materials	Ghana	Previous work by Cal Poly has developed Insulated Solar Electric Cooking (ISEC) whereby a solar panel is directly connected to an insulated, electrically heated cookpot. However, there is a need for cookpots with more power and/or for use during the evening after the sun has set. In this project, these cookpots are being developed through phase change thermal storage capability using Erythritol, with a melting point of 118°C that can store about ½ kWh over the course of the day.
ServedOnSalt	Prototype development of cooker with integrated thermochemical energy storage	Kenya	There is a need for innovative solutions to the challenges of sustainable cooking in refugee settings, especially in sub-Saharan Africa where the environmental impact of large (and rapid) movements of people across borders is most acutely felt. This project seeks to tackle this challenge by developing a portable cooker with a thermochemical heat battery that can be charged using concentrated solar power. The stoves will be charged at charging stations across the camp, and the refugee can carry them home to cook in peace.
Smart Villages	Low Cost solar thermal storage for time-shifted carbon free cooking	Tanzania & Uganda	Heat from the sun for cooking is free. But often food is not prepared at times when the sun shines (e.g. in the evening) or in places where it shines (e.g. outdoors). This has led to low uptake of solar cooking technologies. But if simple technologies can be developed to capture and store heat from the sun during the day, for use later and in different locations for traditional cooking, this should provide a solution which is culturally acceptable and delivers significant development benefits. Current solutions are often over-engineered and so unaffordable (the only solution on the market costs $300 per unit). It is possible to develop systems using less optimal, but much more affordable and less complex components. In this project the performance and efficiency of different components of such a thermal storage cooking system will be investigated, and the most appropriate and complementary low-cost appropriate systems will be selected.

Table 1. Outline data for the projects

We were encouraged by the range of applications to this theme which offered to explore the limited research, to date, into phase change materials and thermal storage. We also received an interesting application from Amperes to develop a circular economy for lithium ion batteries, so all projects explored the options for time-shifted cooking. Below are the successful projects that MECS funded in this space. Their final reports can be found on the MECS website (link)

Learning from Amperes

Amperes used a novel approach to develop locally produced battery storage packs that utilise current e-waste streams thereby creating a circular economy within their target community in Myanmar. A largely rural community with little access to on-grid electricity, they saw the potential to utilise local partners and expertise to produce system storage for local communities. With government plans to provide universal electricity access by 2030 and currently only 1/3 of the population having that access, the need for a storage solution is clear.

There is much to applaud this project which embraces a circular-economy. It uses local supplies and workforce to manufacture the systems and aims to develop a community ownership enterprise with the local community that is amenable and already aware of e-cooking. IP is centrally owned but franchise cooperatives can establish easily.

Their concept uses state of the art technology, which is currently priced out of the market due to high upfront costs, to enable electricity use for more people.

The pilot village was chosen because of its proximity to a domestic airport (1 hour away). The fact that 30-40% of households already use battery technology (albeit lead acid) ensured that there would be interest in using this technology. MECS had already undertaken an e-cook trial in the region which meant that the village understood the ability of these systems.

Current fuel practices noted the use of fuel wood for cooking and water heating, and solar power for lighting.

Upcycled battery tech offers an opportunity to buy affordable batteries that provide greater performance than the currently used lead-acid battery. The assembly procedure is simple and easily taught (AMPERES developed a visual training manual to support training sessions), but it relies on the development of robust processes to ensure safe assembly. They highlighted the need for staff with IT skills as well as a personnel manager to ensure effective communication to staff.

All villagers 'especially young women' were keen to be involved with the assembly process. Whilst many were unfamiliar with techniques such as soldering, they were keen to understand and work. This involvement from women will not only enable greater agency and therefore decision-making abilities for women, but it would also ensure a valuable skill set is filled and established to enable sustainable production.

The concept was largely proved, and the project outcomes were successful. All participants noted that the use of electric cooking enabled significant time savings, protected them from smoke and reduced time on collecting wood. Recording the cooking diary also enabled the householders to become aware of the cost of cooking and '*analyse our budget'.* This gave them greater understanding and power to make decisions. The modular nature of the systems meant that they could be purchased incrementally, and systems could be made bigger for mini grids.

However, the work also raised several issues and barriers that required addressing to enable greater uptake.

- The performance of the battery packs.
  The pilot packs could only provide enough power to enable 3 meals to be cooked a day if certain changes were implemented. The proposed changes included:
  - Taking into account the impact of cloudy days which provide lower energy production via the solar panels; this means the battery packs needed to be larger (and current absence of energy leads to the use of a variety of fuels).
  - In general, the pack size was too small to fit household needs all the time and had to be increased to 2.5kWh, however 5kWh was identified as the optimum size. This raises its own issue of weight (the 2.5kWh system weights 20kg) and has impacts on the distribution of the systems.
  - The use of recycled batteries and associated performance issues related to their charging and the life cycle of the packs was difficult to ascertain. The provision of information on cooking habits to optimise power consumption could overcome this issue.
- A Waste Management policy.
  Public knowledge regarding waste streams are low and may lead to a lack of local supply. A Government-backed Waste Management Policy would go some way to addressing this issue.
- Poor infrastructure
  This included the lack of a grid in rural areas (to supplement battery top-ups), the impact on transportation and the available energy for the production processes related to manufacture of the packs. However, the modular nature of the systems could largely overcome the transport issues, but infrastructure would need to be factored into the siting of any production facility.
- Finally, the unfamiliarity of cooking with electricity led to some issues. Participants noted *'It was hard to use at first, because this is a new experience. But later, we can use it well…'.* Training to encourage use and highlight what can be cooked was recommended (and supports work done by many of the Challenge Fund projects – Kisambara, SOWTech, Pesitho etc).

It is encouraging to see the work done as part of this project, and we note that the benefits seem to outweigh the negatives. Whilst there is still some work to be done to deliver a sustainable system, they have proved the concept but with Government support could offer a real alternative to communities.

Learning from CalPoly

CalPoly too explored the options of a locally produced system that was also low cost. However, their core premise was that in order to keep costs to a minimum, phase-change thermal storage (PCTS) should be implemented as opposed chemical electrical battery storage. By choosing to enhance the Insulated Solar Electric Cooking (ISEC) device that had been developed in 2015, they explored the addition of a phase-change thermal storage capability to enhance usability. Their focus was to enable 0.5kWh of storage over a day for a unit price of about $20 for the thermal storage unit alone. The aim to improve, refine and disseminate PCTS would allow cooking even if the power supply were off and, importantly, enable time-shifted cooking.

The development of the PCTS was done at Cal Poly, while the group established a company (SolCook, LLC) in Kumasi, Ghana to construct and disseminate ISECs. Initially, SolCook produced ISECs without thermal storage (powered by a free-standing 100 W solar electric panel) for dissemination in a grid-connected community. 10 systems were deployed into households for free with a complimentary bag of rice. The recipients were asked to talk about their experiences after four weeks and again after three additional weeks. The chief complaint was lack of power and that they couldn't cook at night (without thermal storage). However, it was noted that all used at least one other form of fuel with the majority (6) using LPG and 4 using coal pots. Most people agreed that the ISEC made cooking easier, it '...helps save cost and energy (gas) and is less destructive'. Reducing the burden of fetching firewood was also noted. Subsequently, SolCook has been constructing ISECs with PCTS and was able to find a manufacturer for the required pots in Accra, allowing pots to be shipped to Cal Poly for construct of the thermal storage unit. Recently, the company has refused to make more pots because of low order numbers, so SolCook is interviewing other companies. Additionally there was difficulty importing 100 kg of erythritol from China for $600 to purchase and then another $600 to be released at the port.

The flow of heat depends greatly on the temperature difference between the PCM (Phase Change Material) and the food. For instance, if the PCM is 190 C (the maximum temperature to avoid thermal degradation) the power flow to cold water is near 2000 W. However, this drops to less than 50 W when the food is near boiling and the PCM is crystalizing near 118 C. This was originally viewed as a problem, but it can also be considered an asset because it allows the PCM to ration the stored energy, allowing boiling times of several hours. This same aspect protects food left in the ISEC from burning. This loss of power at lower PCM temperature is partially due to the crystallization of solid erythritol (a thermal insulator) onto the cookpot's surface, insulating the cookpot from the hotter liquid erythritol. Shredded aluminum was added to the PCM in order to increase the thermal conductivity of the solid erythritol. However, the shredded aluminum impedes the convection of the liquid erythritol, reducing the thermal flow when the PCM is very hot. Thus, it may be best to have no shredded aluminum and recognize that the ISEC with PCTS has a high power regime when the PCM is hot, and a low power regime when the PCM is crystalizing (good for long slow cooking). The greatest drawback of an ISEC with PCTS is that it doesn't work well on days with no sun. A recently added $10 electrical power source provides the ISEC with low power heating from grid electricity.

Issues with corrosion, diode failure and locally built USB charging circuits were also raised and have led to further research. This has taken the form of a greater understanding of the corrosion, resulting in a return to resistive heating instead of the use of diodes. Additionally USB ports from China replaced those made from diodes. While this goes against the projects original aims to enable local production, the trade-off between shipping in and local production was deemed beneficial to the overall project providing a system that offers the low-cost usability options set out at the start. Whilst this project still has some issues to overcome, it made great strides in the understanding the practical issues of using this system. The experience of SolCook highlights the issue of the supply chain (as noted by many other TRIID projects including Bidhaa Sasa, Pesitho, Amperes, CREATIVEnergie etc) and points to the need for system design to cover household cooking with a reliable power supply delivering a system that is low-cost and provides the use ability that cooks demand.

Learning from Served on Salt

Whilst CalPoly was able to get their systems out to participants, ServedOnSalt (SOS) did much of their work within the lab. Their very innovative and alternative approach was to use thermochemical storage with salt de- and rehydration to provide a low cost, energy storage as a component of a clean cooking alternative. Although mainly lab based this research also considered the target audience, supply chain issues once the system was established and ease of maintenance – all key factors for a viable scalable clean cooking solution.

With the focus on time-shifted cooking, the work set out to establish whether a 2kg salt solution could bring 2 litres of water to boil and enable the cooking of 500g of beans. It looked at the technical issues of the system focussing on the impact of cyclability of the thermochemical solution and the speed of dehydration for practical use.

The thermochemical storage medium aimed to store energy for a longer period than phase change thereby reducing the need for batteries and avoiding their inherent safety and handling issues. Its principle is based on the fact that salt hydration provides '*high theoretical energy density with unlimited storage time'*. The importance of the word theoretical was the key focus here.

SOS addressed the issue of charging their system noting that a solar charging hub could provide employment for current traditional fuel suppliers who are located close enough to users to encourage pick up of charged units. Siting such a hub would be ideally focussed in a densely populated area such as the Kibera community in Nairobi. In these areas, many of the inhabitants bought beans from street 'hotels' where '*entrepreneurial women cook big portions of bean or chapati*'. Their system therefore needed only to be able to warm food.

This information provided a focus for SOS's research. However, they experienced many technical issues with the system, agglomeration of the salt being the main issue. This led to reduced usability and highlighted the importance of ensuring the right metal was used to minimise corrosion. The original concept proposed using a nano-coated salt, however the requirement of complicated processes to enable hydration meant this would not be suitable for low-cost production. These hydration complications would increase the costs of production of the unit, which needed to cost less than 100KSH/day to be able to compete with current options.

The technology has not yet reached its potential, largely due to the challenges associated with agglomeration of the salt solution. The authors note *'. a decent amount of work and development are needed before having a market ready appliance*' but they feel, that with further research, a solution can be found.

Learning from Smart Villages

The final project in this theme was undertaken by Smart Villages. Again, they explored the performance and efficiency of a low-cost thermal storage cooking systems for rural off-grid users in Uganda and Tanzania.

In Uganda, three-stone stoves are used to cook one main meal a day, usually at lunchtime or early afternoon. It typically takes 2 hours to cook and the community does not pay for wood, but it is becoming scarce to source, so collections times are increasing.

Their goal was to find a clean cooking solution which costs less than $50 for the storage system, could cook a full family meal when charged and retained 80% of its heat for at least 4 hours.

They undertook this work from several perspectives but first reviewed currently available solar cookers and then solar collectors to heat a storage medium. This was based on the premise that high and reliable insolation would allow effective use of solar cookers. They explored the useability of this technology to understand why uptake was so low.

They found that many solar collectors exist, ranging from under £5 each to £120, however, they found that the lower the cost, the greater the instability and the increased support that was required to enable solar collection. Even minor winds made them unstable and thermal performance varied with many options unable to heat a thermal storage load above 300 degrees (and they also posed a safety issue).

On further examination, they found that solar concentrators that enable radiated energy to be focussed into a smaller area would be preferable and considered the use of a low-cost Fresnel lens (unavailable in country and costing $150) and a two mirror system which would improve safety but would increase the issue of robust construction and therefore weight.

They concluded both options were unsuitable for domestic adoption.

A review of alternative heat sources, including pyrolysis and PV panels was highlighted. Both offer viable solutions to charge thermal storage elements, but both have drawbacks such as the inability to time shift cooking (with a pyrolyser) or increased cost (with PV panels).

For the thermal storage options, the focus was on a low-cost system which required minimal change to current cooking practices. Many options were assessed, from locally found stone to PCM but the fact that different materials were available in different countries meant that a variety of options would be required. Stones and low-tech options, whilst cheap, needed to be bulky to be effective. Insulation, in the form of mineral wool, aluminium silicate blanket and vermiculite all performed similarly but nothing could perform to the required standard of retaining 80% heat over 4 hours. Heat losses were over 50% with all materials. This finding meant that '*the thermal storage medium must be charged with at least double the amount of energy needed (including losses) to achieve the ultimate cooking test*.'

Further considerations of the limitations of thermal storage led the authors to note that mini-grids or solar reflector 'farms' on the edge of villages may offer a solution to HH's storage. These farms could provide multiple charging of thermal storage units when demand is high. This would solve the problem of energy availability, storage of excess energy and cost. It echoes the thoughts of SOS who note the benefits of a similar system to provide power to communities in Kibera. Smart Villages felt this would be '*a very promising [system]'* offering local employment and continuity of supply. The solar reflector farm and charging system would enable users to pay a subscription, of approx. £0.7/day and enable the entrepreneur to pay back the capital costs within 3 years. They make it clear that this system will only work where biomass is not 'free'.

The work highlighted that whilst the use of PCM was considered the best option for storage, it was expensive, had to be imported and come with technical issues not yet overcome by others (CalPoly, SOS, SOWTech). The need for insulation was also noted to reduce the loss of energy in the system and raises issues of affordability and supply. Other, cheaper, solutions needed to be made more robust which ended up large and immobile.

In conclusion, Smart Villages note '*All of the best and most portable materials need to be imported*'. This relates to PV panels, PCM material, insulation and metal for solar collectors making cost an increasing issue.

From a cooking culture perspective, the authors note that '*in an ideal world, pots would be insulated and pressurised*'. The use of insulation around the cooking pot, that did not impede cooking, was the most attractive to the community.

Conclusion

In conclusion, these four studies explore very different options but show much overlap between them.

Amperes demonstrate that a locally supported production facility can utilise a current waste stream but that supply chain issues and the lack of a waste management policy could hinder take up. Calpoly have identified that supply issues are a problem for locally produced systems and both they and Smart Villages accept that the benefit of importing outweighs the costs in producing a robust system that offers a robust system with longevity of use.

ServedOnSalt had an innovative approach exploring dehydration of salts but failed to take the idea beyond proof of concept. The theoretical benefits of this material are considerable so getting it to work effectively would offer a significant step forward.

The importance of insulation is highlighted by all projects both from a thermal storage potential as well as for the cooking pot and is echoed in work undertaken in different projects such as SOWTech, Kachione, UIU. This work offers great potential but requires further work to make it an effective solution.