# Capacity Building for Solar Agro-processing in the Pacific

FINAL REPORT

Prepared by

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For

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## ABOUT THE AUTHOR(S)


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Stewart Craine has worked in renewable energy since 1999, including project management of the construction of microhydro power minigrids in remote regions of rural Nepal, India, Papua New Guinea and Fiji, large scale wind power projects in Australia, GIS mapping of Australia and emerging markets for commercial development of renewables, offgrid kW and MW scale hybrid system design, and development of residential lighting and phone-charging 1-15W solar electricity systems for the poor. Stewart has co-founded and operated two social enterprises, Village Infrastructure Angels (UK) in 2012 and Barefoot Power (Australia) in 2005, and has raised over $10 million in equity, debt and grants to help millions of villagers gain access to electricity. Through his work at VIA, he is currently focused on growing commercially viable lending opportunities of cash and assets to the poor in remote villages around the world, so they may have access to the infrastructure such as energy and water technologies that are critically needed to reduce long-term poverty.

This report is authored solely by Stewart Craine, and any errors contained herein are solely his, and not those of VIA or IRENA.

## ACKNOWLEDGEMENTS


The authors would like to thank Kavita Rai and Ilham Talab from IRENA for their support for this project, and to guide its evolution. Thanks are also given to Mr Greg Denn from Project Support Services who assisted in sourcing and installing the mills and training entrepreneurs in Papua New Guinea; to Sandrine Wallez for logistical support of product import to Vanuatu and entrepreneur training assistance. Thanks to all others who also contributed to the project.

# EXECUTIVE SUMMARY

In April 2014, IRENA contracted Village Infrastructure Angels (VIA) to undertake a 5.5 month project to build capacity of entrepreneurs in Vanuatu and Papua New Guinea to design, build and operate at least 2 solar powered agro-processing mills, evaluate the impact and disseminate the findings via local workshops for stakeholders.

The Pacific Islands region face large import bills for petroleum products, of which kerosene that is used for lighting in many offgrid villages is one such product, and diesel plus gasoline for small generators are two others. In particular, four countries in the Pacific with low electrification rates, including Papua New Guinea (12%), Solomon Islands (14%), Vanuatu (28%) and Kiribati (44%), are particularly vulnerable to oil price fluctuations. Replacing these imports with local renewable energy sources can reduce this vulnerability. Solar power is one of several renewable energy sources that can be used to replace these three fossil fuels, and while the use of white LEDs for lighting has been rapidly accepted as a viable market transformation opportunity, little attention has so far been paid to daytime uses of energy for the poor, which are often related to farm productivity, such as agro-processing, refrigeration and communication for improved market access.

Over 70% of food in developing countries originates from over 2 billion people who are working on 500 million smallholder farms globally, most of which are less than 2 hectares in size. 870 million people lack adequate access to sufficient food, and ironically, most of these are smallholders farmers. In many villages in the Pacific, manual labour still dominates agro-processing, and reducing the time of mostly women spent on these laborious manual tasks could open up opportunities for increased productivity and income-generating opportunities. Indeed, if 1 hour of manual labour could be saved per household in a million rural households of the Pacific that currently lack access to electricty, as many working hours of productivity would be unlocked as the entire workforce of Canberra, Australia's capital city. Globally, if 1 billion people or 250 million households (and women) could free up this productive hour, it would be equivalent to the workhours of the entire workforce of the UK.

Rural electrification and "access to electricity" is not defined by any organization as the provision of lighting and phone-charging only, but must also include productive end uses of electricity such as agro-processing. As long as women and children continue to beat crops with sticks and stones, the United Nations' goal of attaining Energy for All by 2030 cannot be attained. While 2012 was the United Nations' International Year for Sustainable Energy for All, 2014 is the UN International Year of Family Farming, so it is timely to explore the role energy plays in smallholder agriculture. The leading staple foods of the global poor are rice, maize and cassava, all of which must be processed before consumption. This is also true in the target geography of this project, the Pacific Islands. The vast majority of households undertake food processing in one of two ways - manually, using human effort, or by paying for services from a local mill, which is powered from central grid (or large minigrid) electricity or, in off-grid situations, almost always by diesel engines.

In most offgrid villages, agro-processing is either manual or local mill is belt-driven by a diesel engine (and no electricity is produced). These are generally of 3-5 kW capacity and can process a 30-50 kg bag of crop in 10 minutes, or at a rate of about 200 kg/hour. Households often spend as much on transport to and from agro-processing mills as what is paid for the processing. An overview of

manual methods of agro-processing have been presented, including hulling rice, shelling corn/maize, grinding flour, grating coconuts and cassava, and others. Such manual labour often requires 1 hour per day to process 1-2 kg, from mostly women and children, but sometimes men. In the Pacific, and other regions, it is typically men who will operate a diesel-powered mill rather than women.

In recent years, the price of solar power has dropped dramatically, making it more competitive with diesel than ever before. At $1/watt and 1500 hours of productive power per year, the cost of energy from solar over 10 years is approximately $0.07/kWh, or $0.14/kWh over 5 years. Diesel, at $1/litre and 3 kWh/litre efficiency has a cost of $0.33/kWh, and prices are often higher in remote islands. Initial estimates suggest 200W - 2000W solutions for solar agro-processing are possible for $500-$5000, which would process 20-200 kg/hour. A typical tariff for processing is often around $0.03/kg, so a mill utilizing an average of around 2.5 hours/day of solar power could process 50-500 kg/day, generating $1.50-15.00/day of gross revenue, or $500-5000/year. Similarly, 1-2 litres/day of diesel fuel costing $300-1000/year can be saved. Thus, payback periods of 2-5 years are possible.

The project planned to install 2 mills to benefit 50 customers and train at least 5 entrepreneurs. Two workshops should be conducted to deliver lessons learned and a 3-5 minute video should be produced. The project tested 10 mills and installed 6 mills (two with real-time monitoring), 8 entrepreneurs were trained, and a total of 62 customers used the mill or purchased product produced by the mills. Workshops in Port Vila (Vanuatu) and Lae (PNG) attracted 39 participants, with at least 100 updated via email. At least 4 concrete commercial opportunities and customers were identified focused on rice hulling and coconut grating, and interest in the mills demonstrated was generally very strong. A video of 9 minutes length has been created and is viewable online.

A desktop analysis of solar agro-processing solutions concentrated on staple crops more than cash crops to ensure widespread interest and a focus on reducing daily manual labour by women. This found 10 major crops and processes where solar alternatives offered a solution. A “power gap” was identified, above the maximum power a villager can put into manual processing (100-200W) and below the minimum size diesel powered mill (2000W). This 200-2000W range can be filled by small (200-750W) and larger (750-2000W) solar solutions that will serve the needs of small groups of 5-15 households or larger groups of 15-50 households. The median sized village in the Pacific is also around 30-50 households, but diesel mills are found in larger 100-300 household villages, so solar milling opens the door to small villages having a mill in their own village, reducing travel costs. We estimate 2000 small offgrid diesel mills are sold annually in the Pacific at a market value of $4 million per year, but more solar mill units could be sold due to their smaller size, reaching smaller villages.

Survey results indicated that the perceived benefits of solar milling by potential customers included the obvious results of diesel fuel savings, but just as importantly, far lower maintenance and increased reliability (yet to be proven in the field), women-friendly technology compare to diesel, reduced travel time and costs, and the ability to increase prices of product due to the “green” solar processing involved. The cost of the solar mill installations was not part of the project budget. Part of the project was to help entrepreneurs mobilize investor capital and borrow funds over 3-5 years for the mills. This was achieved, with Rotary Melbourne putting in a AU$10,000 3-year 5% p.a. loan for the project. In the future, these projects may be refinanced on Kiva, spreading the lending risk over a crowd of investors and reducing the investors’ interest rate to zero.

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## GLOSSARY OF TERMS AND ABBREVIATIONS

The following glossary of terms and abbreviations are specific to this report.

| | |
|---|---|
| **ACTIV** | Alternative Community Trade in Vanuatu (VIA field partner in Vanuatu) |
| **Ah** | Amp-hour (the typical capacity rating of a battery) |
| **$CO_2$** | Carbon dioxide |
| **DOE** | Department of Energy (in Vanuatu, unless specified otherwise) |
| **IRENA** | International Renewable Energy Agency |
| **kW** | Kilowatt (a measure of power) |
| **kWh** | Kilowatt-hour (a measure of energy) |
| **NARI** | National Agricultural Research Institute in PNG |
| **NGO** | Non-government organization, also sometimes referred to as 'civil society' |
| **PNG** | Papua New Guinea |
| **PSS** | Project Support Services (VIA field partner in PNG) |
| **PV** | Photovoltaic |
| **SHS** | Solar home system |
| **SIDS** | Small Island Developing States |
| **VIA** | Village Infrastructure Angels Ltd |
| **WB** | World Bank |
| **Wp** | The peak power in Watts of a solar panel |

# 1 PROJECT BACKGROUND

The following sections give the background of the project, details of the project partners, the overall rationale for undertaking the project, a description of how the project will be undertaken, project management, tasks, milestones and deliverable reports and outcomes.

## 1.1 BACKGROUND

The short summary of the original terms of the project is given in Table 1. A small deadline extension was agreed to by email to complete by 15th October 2014.

**Table 1: Project Summary**

| | |
|---|---|
| Project name | Solar Agro-Processing for the Pacific |
| Project duration | 5.5 months |
| Start date | 15th April 2014 |
| Completion date | 30th September 2014 |
| Cost of the project US$ | US Dollars Forty Thousand Only ($45,000) |
| Geographical scope | Vanuatu and Papua New Guinea + possible expansion in other Pacific Small Island Developing States[1] – Kiribati and Solomon Islands. |

## 1.2 PROJECT PARTNERS

Descriptions of the project partners are given in the following sections.

### 1.2.1 IRENA

The International Renewable Energy Agency (IRENA) is mandated as the global hub for renewable energy cooperation and information exchange by 111 Members (110 States and the European Union) and 49 Signatories. Formally established in 2011, IRENA is the first global intergovernmental organisation to be headquartered in the Middle East. IRENA supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

### 1.2.2 VILLAGE INFRASTRUCTURE ANGELS

Village Infrastructure Angels (VIA) is a group of concerned investors and experts that seek to reduce poverty in developing countries by investing in critical infrastructure assets like electricity, water, agro-processing equipment and other technologies. Current growth in village energy solutions has

[1] States listed are Members or Signatories of IRENA as of date of signing this agreement.

focused around cash sales to the poor, which is limited to the richest of the poor and 5-30% market penetration. VIA will focus on 1-3 year project finance to remove the upfront cash cost barrier, and demonstrate that 70-100% of households can afford properly financed infrastructure, which they will ultimately own, whilst also delivering a commercial return on capital to investors. VIA aims to mobilize $10-20 million of angel and impact investor capital in its first 3 years to assist 10,000 households to gain access to electricity, including risk guarantees and grants to absorb early stage learnings and defaults.

## 1.3 PROJECT RATIONALE

The Pacific Islands region, and particularly Small Island Development States (SIDS) face large import bills for petroleum products, of which kerosene that is used for lighting in many offgrid villages is one such product, and diesel plus gasoline for small generators are two others. In particular, four countries in the Pacific with low electrification rates, including Papua New Guinea (12%), Solomon Islands (14%), Vanuatu (28%) and Kiribati (44%), are particularly vulnerable to oil price fluctuations. Replacing these imports with local renewable energy sources can reduce this vulnerability.

Solar power is one of several renewable energy sources that can be used to replace these three fossil fuels, and while the use of white LEDs for lighting has been rapidly accepted as a viable market transformation opportunity, little attention has so far been paid to daytime uses of energy for the poor, which are often related to farm productivity, such as agro-processing, refrigeration and communication for improved market access. In many villages in the Pacific, manual labour still dominates agro-processing, and reducing the time of mostly women spent on these laborious manual tasks could open up opportunities for increased productivity and income-generating opportunities. Indeed, if 1 hour manual labour could be saved per household in a million rural households of the Pacific that currently lack access to electricity, almost as many working hours of productivity would be unlocked as the entire workforce of Canberra, Australia's capital city. Globally, if 1 billion people or 250 million households (and women) could free up this productive hour, it would be equivalent to the workhours of the entire workforce of the UK, France or Italy.

Significant challenges exist in transforming the offgrid fossil fuel markets towards a commercially viable renewable energy market, including small populations, geographic dispersion in the worlds' largest ocean, relatively high transportation costs, and susceptibility to natural disasters. To assist in overcoming these barriers, IRENA developed a capacity building initiative for the Pacific Islands, for the 2012-13 Work Programmes. Rural electrification and "access to electricity" is not defined by any organization as the provision of lighting and phone-charging only, but must also include productive end uses of electricity such as agro-processing. As long as women and children continue to beat crops with sticks and stones, the United Nations' goal of attaining Energy for All by 2030 cannot be attained. Such investments in rural villages may have longer payback periods than lighting and phone-charging, and thus may be harder to mobilize investment for, but with rapidly decreasing costs for solar power, longer-lasting batteries and smart monitoring technologies, this project aims to demonstrate such hurdles are not insurmountable.

The leading staple foods of the global poor are rice, maize and cassava, all of which must be processed before consumption, and this is also true in the target geography of this IRENA project, the Pacific Small Island Developing States (SIDS). The vast majority of households undertake food processing in one of two ways - manually, using human effort, or by paying for services from a local mill, which is powered from central grid (or large minigrid) electricity or, in off-grid situations, almost always by diesel engines.

There are some exceptions - in the Himalayas, most agro-processnig happens from centuries-old water mills called ghattas/gharats, or from modern microhydro mills. But in most offgrid villages, agro-processing is either manual or local mill is belt-driven by a diesel engine (and no electricity is produced). These are generally of 3-5 kW capacity and can process a 30-50 kg bag of crop in 10 minutes, or at a rate of about 200 kg/hour. Households often spend as much on transport to and from agro-processing mills as what is paid for the processing.

**Figure 1: Typical diesel belt-driven maize mill and rice mill**

Manual processing is laborious, and often requires one hour per day or more for the various processes required to prepare crops into food ready for cooking. The process for maize involves shelling (removing kernels from the sun-dried corn cob), grinding (usually between two stones) and winnowing (removal of the lighter kernel husk pieces from the heavier/denser corn meal pieces by tossing in the air so the wind blows the husk away). Similar for rice, the grains must be removed from the stalk (threshing), then the husk from the rice (hulling) and sometimes this is followed by polishing of the rice and/or separating the bran. Cassava is cleaned, cut into chunks and then pounded into a very coarse flour.

These processes are shown in Figure 2. Manual corn shellers and grinders can often cost $30 and last only 6 months, meaning an average of $1/week is spent on such tools, similar to expense on kerosene lighting.

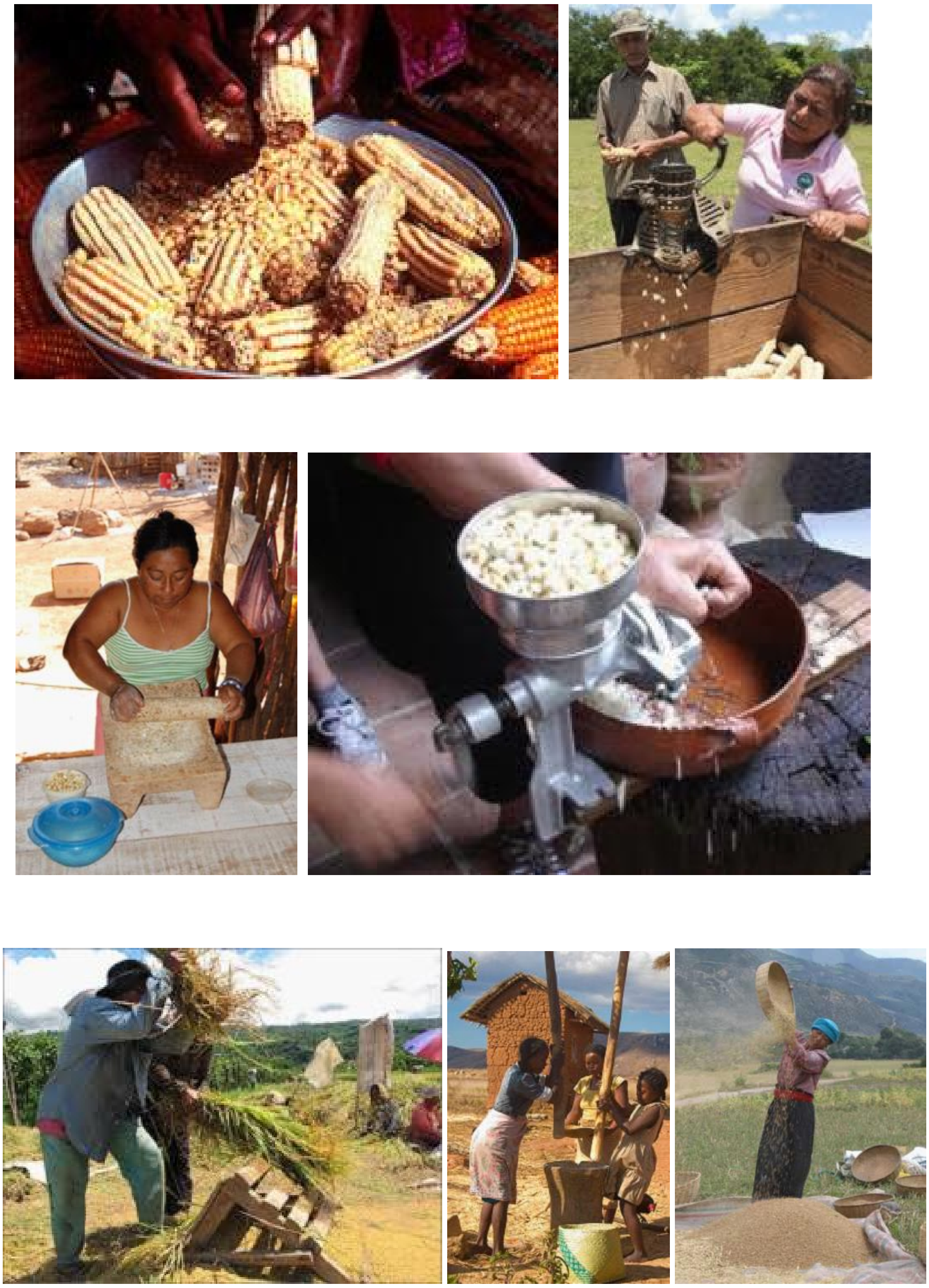


**Figure 2: Manual processes for maize and rice. Cassava is also beaten with poles.**

## 1.4 PROJECT DESCRIPTION

In recent years, the price of solar power has dropped dramatically, making it more competitive with diesel than ever before, and even affordable for those who have used manual methods, as these households state that time saved could be used to expand their garden and grow more crops, or have more time to make handicrafts or to do weaving and thus generate more income. At $1/watt and 1500 hours of productive power per year, the cost of energy from solar over 10 years is approximately $0.07/kWh, or $0.14/kWh over 5 years. Diesel, at $1/litre and 3 kWh/litre efficiency has a cost of $0.33/kWh. Even with higher installed costs per watt, the payback period of solar displacing diesel is attractive.

Agro-processing is a daytime activity, and can often be done on a flexible schedule, so the potential of having little to no battery storage by directly driving motors from solar panels is appealing (DC motors if inverters are not used, AC motors if they are). This "direct drive" approach has been used for solar water pumps, which pump water only while the sun is shining. Such systems have successfully displaced a large number of diesel generators that were previously used for this task. One example of solar milling can be found at www.solarmilling.com, and a 1kW version is shown in Figure 3 below. However, a preliminary investigation indicates that a) grinding is not the only process required, and b) various costs and designs may lead to more optimal solutions. Given other uses of energy, and fluctuations in solar energy during the day or week, it is not necessarily optimum to have a battery-free design.

**Figure 3 - A 1kW battery-free "direct drive" solar milling system**

In this project VIA will investigate the opportunities for agro-processing in the Pacific using renewable energy, with a primary focus on solar power, to reduce manual labour of women and children and dependency on small diesel generators. Initial estimates suggest 200W - 2000W solutions are possible for $500-$5000, which would produce 20-200 kg/hour. A typical tariff for processing is often around $0.03/kg, so a mill utilizing an average of around 2.5 hours/day of solar power could process 50-500 kg/day, generating $1.50-15.00/day of revenue, or $500-5000/year.

## 1.5 OBJECTIVES AND OUTCOMES

The project objectives include the following:

- Increase access to productive electricity in rural areas, using affordable, clean, reliable and efficient technology of solar power as an alternative to expensive, hazardous diesel.

- Reduce manual human energy spent on agro-processing, saving time of households (mostly women and children) for more productive uses of time.
- Build local entrepreneurship capacities to assist transition from donor support to sustainable markets.
- Enhance sustainability of off-grid energy investments through enhancing operation and maintenance programmes.
- Strengthen project’s supply chain for operation and maintenance.
- Contribute to reducing black carbon emissions of diesel generators.
- Contribute to the SE4ALL High Impact Opportunities under Action Area B: Distributed Electricity Solutions.
- Increased awareness from government and non-government stakeholders of using centralized solar power for non-lighting productive uses
- Demonstrate the efficiency of VIA's model of long-term supplier credit and lease-purchase contracts to deliver credit for renewable energy business activities to importers, local distributors and consumer (village households).

The intended project outcomes include the following:

1. At least 50 persons benefiting from the installation of at least 2 solar agro-processing mills, which may be any of (but not limited to) rice hullers, coconut oil expeller + grater, coffee pulper, flour grinder (for cassava or maize) or mincer (for meat or kava);

2. At least 5 entrepreneurs trained and able to manage a solar agro-processing business successfully within project period (including reserve/support entrepreneurs);

3. Attract additional expressions of interest for investment to expand these pilot projects to larger scale. Actual committed finance is desirable, but not likely achievable within the short project period and given the early-stage nature of the technology, which may need 12 months or more of successful field operation before further investment can be committed;

4. Two workshops in two Pacific Island countries (most likely PNG and Vanuatu) to disseminate the findings and experience of the solar agro-processing mills, resulting in evidence of requests for further engagement to undertake more projects in either country;

5. A short video describing the project in the context of other rural electrification services supported by IRENA, such as solar lighting and phone charging

One solar refrigerator for fish preservation or other productive use may also be optionally included.

## 1.6 PROJECT MANAGEMENT

Under this agreement, IRENA will support capacity building activities targeting elimination of diesel and manual labour in 50 households of Vanuatu and Papua New Guinea, while developing local entrepreneurship capacities. VIA proposes to undertake (in partnership with its network of angels) the role of infrastructure investor, relieving all other supply chain partners (suppliers, importers, distributors) of the need to extend their credit to consumers, and also relieving microfinance institutions and local banks of the need to extend such credit.

illustrates the framework of the project, where VIA plays the role that angel investors often undertake in Western markets to bring innovative but "high risk" new technology to market. In the Pacific, few if any such angel investors exist, and those that do would not likely find much appeal in a business model of long-term loans (3-5 years) to rural households.

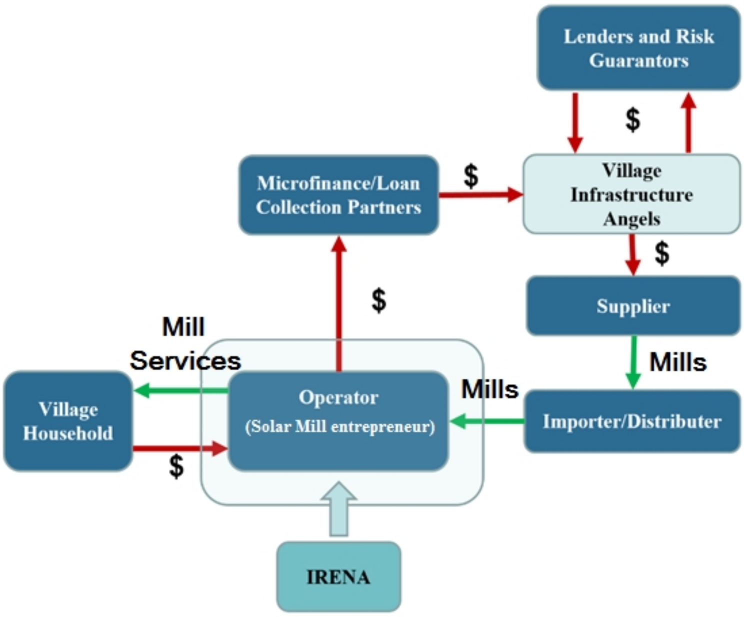



Figure 3 : Project Framework of the VIA Long-term Supplier Credit model

VIA will lend the infrastructure to villages via a lease-purchase contract over 3-5 years, such that ownership of the infrastructure is transferred to the villagers at the end of the lease if all payments have been made. A buyout price for the infrastructure will be offered, so the entrepreneur can buy the assets of the business at any time during the lease. VIA and its angel investor network reserves the right to refinance the project at any time during the project, or thereafter (eg. by putting the project online via www.Kiva.org or similar crowdfunding platforms).

The funding from IRENA will support the capacity building component of the project through the training programmes to entrepreneurs. VIA will mobilize the capital for the hardware costs and freight costs to the final destination.

The Project Agreement Managers will be responsible for making, by consensus, management decisions for the project and for holding periodic reviews. Should the Managers fail to achieve consensus, the final decision making rests with IRENA. Each Party will designate a Project Manager for the day-to-day management and decision making of the project. The Project Managers, supported by the Assistant Manager, will ensure that the project/activity produces the results specified in the project document, to the required standards of quality and within the specified constraints of time and cost. The Project Coordinator will ensure timely and effective implementation of the agreement. The Project Manager(s) of VIA will prepare a mid-term report and a final report, both technical and a financial summary.

The experience of VIA has been submitted to IRENA previously. The experience of Greg Denn includes over 15 years of selling manual and diesel-driven small scale agro-processing equipment in Papua New Guinea, as well as larger systems and various solar-powered products (including importing Barefoot Power products, amongst others). More details about Greg's company Project Support Services PNG can be seen on www.psspng.com.

**Table 2: Project management and responsibilities**

| Person assigned | Responsibilities | Contact information |
|---|---|---|
| Kavita Rai | *Project manager, Client (IRENA)* | krai@irena.org |
| Apisake Soakai | *Project coordinator (IRENA)* | asoakai@irena.org |
| Ilham Talab | *Assistant manager (IRENA)* | italab@irena.org |
| Stewart Craine (VIA) | *Project manager, Contractor and capital raising* | stewart@villageinfrastructure.org |
| Kim Chen (VIA) | *Training and installation in Vanuatu* | kim@villageinfrastructure.org |
| Greg Denn *(PSSPNG)* | *Engineering advice + training & installation in PNG* | greg@psspng.com |

## 1.7 TASKS AND MILESTONES

The detailed tasks of the project are outlined as follows:

1. **Review of renewable processing alternatives:** a procurement and engineering review will be undertaken of alternatives to diesel-driven agro-processing equipment and refrigeration

2. **Stakeholder survey of technology preferences :** Introduce local industry, government, NGOs and potential investors to the concept, gather feedback on preferences of technology to use in pilot project

3. **Capital Raising for hardware and freight costs:** At least $5000 of investment capital will be raised to pay for the installed cost of at least 2 agro-processing mills

4. **Importer evaluation and training:** potential importers for the equipment will be identified, and an importer selected to undertake logistics, who will be trained

5. **Installation training session for first mill:** Train at least 2 local entrepreneurs on operation & maintenance of the first agro-processing mill. Also run a local workshop with the

community to build awareness of the limitations/capacity of the machine, and tariffs to pay. Meet other local stakeholders and advise of installation.

6. **Installation training session for 2nd mill:** Train at least 2 local entrepreneurs on operation & maintenance of the second agro-processing mill. Also run a local workshop with the community to build awareness of the limitations/capacity of the machine, and tariffs to pay. Meet other local stakeholders and advise of installation.

7. **Monitoring and Evaluation field visit:** a field visit to monitor technical performance, including a 2nd training for entrepreneurs for business skills and household/consumer feedback on services delivered

8. **A short video:** A 3-5 minute video will be created to explain the concepts used for this model of rural electrification, integrating services of lighting and phone-charging with productive services such as solar agro-processing.

9. **Reporting – Final Report:** VIA will provide a paper including case study on the performance of the model (fee collection rates, diesel substitution rates, etc), its direct measurable outcomes, and scope for replicability and scaling up.

# 2 PROJECT DESIGN AND RESEARCH

## 2.1 MARKET ANALYSIS

### 2.1.1 GLOBAL AGRO-PROCESSING MARKETS

Over 70% of food in developing countries originates from over 2 billion people who are working on 500 million smallholder farms globally, most of which are less than 2 hectares in size. 870 million people lack adequate access to sufficient food, and ironically, most of these are smallholders farmers. Meanwhile, just as many people globally are dying from illnesses related to excessive food consumption, and rich countries throw away as much food as the entire food production of Africa[2]. Low food productivity per hectare in Africa and South Asia is generally regarded to be due more to a lack of inputs (irrigation, fertilizer, etc) and subsidies than any inherent advantage large farms have over small farms[3], particularly for more labour intensive crops. While 2012 was the United Nations' International Year for Sustainable Energy for All, 2014 is the UN International Year of Family Farming[4], so it is timely to explore the role energy plays in smallholder agriculture.

Energy use in smallholder farms can be in several forms, including providing power for irrigation pumps, using pedestrian tractors to plough the fields, using machines to accelerate harvesting, processing of the crop to add value and/or to make staple foods edible, transport of agricultural goods, packaging and cold-chain refrigeration solutions to assist with food preservation. Indirect uses of energy can also include providing power to mobile phones and communication equipment to improve farmer training programs, access to market data and linking suppliers with customers. Even the Gates' Foundation has recognized by its 2012 Grand Challenge for Global Health project on Labour Saving Innovations for Women Smallholder Farmers[5] that energy for agriculture has positive health benefits as well, and rural women are already time-poor, overburdened with daily tasks.

In short, without access to modern energy, it is difficult for a smallholder farmer to deliver competitive agricultural produce, whether for subsistence living or for cash trade in local and international markets. From these varied uses of energy for smallholder agriculture listed above, this project focuses on shifting the processing of crops from manual to mechanized to reduce womens' manual labour, rather than increasing food security via increased productivity or market linkages. By our estimate, if one hour of time can be saved for 250 million women and households that lack access to electricity today, the productivity of 30-40 million people can be released, which is the productivity of the entire UK workforce. Given the daily need for food, our focus is more on the important few crops used for staple foods and survival, than for the many more varied cash crops.

Globally, just 15 crops provide 90% of the world's food energy intake[6] (excluding meat). The main families of staple foods include cereals (wheat, rice, maize/corn, barley, rye, sorghum, millet), tubers

[2] http://www.fairtrade.net/fileadmin/user_upload/content/2009/news/2013-05-Fairtrade_Smallholder_Report_FairtradeInternational.pdf
[3] http://wle.cgiar.org/blogs/2013/02/07/african-agriculture-does-size-really-matter/
[4] http://www.fao.org/family-farming-2014/home/main-messages/en/
[5] http://gcgh.grandchallenges.org/Explorations/Topics/Pages/WomenSmallholderFarmersRound10.aspx
[6] http://en.wikipedia.org/wiki/Staple_food

and roots (cassava/manioc, potato, sweet potato, yams, taro), legumes, pulses and oilseeds (soybeans, lentils, canola/rapeseed, palm fruit) and key fruits and vegetables (bananas, plantain, coconut, tomato, etc). The top 10 staple foods that feed the world are shown in Table 3. The top 3, maize, wheat and rice, account for 65% of world food consumption and feed over 4 billion people. Cassava is also a well-respected crop for food security, able to grow in harsh conditions with a minimum of input, and which can also displace imports of wheat flour and potatoes.

**Table 3: Top 10 staple crops of the world**

| | | World production 2008 | Average world yield 2010 | World's most productive farms 2012[13] | |
|---|---|---|---|---|---|
| *Rank* | *Crop* | *(metric tons)* | *(tons per hectare)* | *(tons per hectare)* | *Country* |
| 1 | Maize (Corn) | 823 million | 5.1 | 25.9 | Saint Vincent and the Grenadines |
| 2 | Wheat | 690 million | 3.1 | 8.9 | New Zealand |
| 3 | Rice | 685 million | 4.3 | 9.5 | Egypt |
| 4 | Potatoes | 314 million | 17.2 | 45.4 | Netherlands |
| 5 | Cassava | 233 million | 12.5 | 34.8 | India |
| 6 | Soybeans | 231 million | 2.4 | 4.4 | Egypt |
| 7 | Sweet potatoes | 110 million | 13.5 | 33.3 | Senegal |
| 8 | Sorghum | 66 million | 1.5 | 86.7 | United Arab Emirates |
| 9 | Yams | 52 million | 10.5 | 28.3 | Colombia |
| 10 | Plantain | 34 million | 6.3 | 31.1 | El Salvador |

***Ref:*** **http://en.wikipedia.org/wiki/Staple_food**

Different crops dominate in different geographies. Asia depends mostly on rice, while Africa depends more on maize and cassava, while Western countries grow wheat which grows best in less tropical regions. In the Pacific Islands, the focus geography of this project, dominant crops also vary a little from country to country, but 8 core staple foods in the Pacific are generally sweet potatoes, cassava, yams, sago, taro, plantains/bananas, coconut and rice[7]. Wheat is often imported, but is eaten more in urban areas than rural areas. Meat, fish, fruits and vegetables complement these 8 core staples. Key cash crops of the region include coconut/copra, coffee, cocoa, palm oil and sugarcane. As an example of variation, cassava makes up 6-12% of produce in PNG and Solomon Islands where sweet potato dominates[8], whereas in Vanuatu cassava, yams, taro and banana dominate [9].

Wheat (and most other cereals), rice and maize must always be processed before eating, thus making agro-processing a necessary part of daily life for rural villages. However, root vegetables (mostly boiled) dominate the Pacific Islands' diet, so food processing is less important to survival in the Pacific than in other regions of the world. However, local needs for food processing do become apparent. In Vanuatu, yams and cassava are mostly finely grated before being fried, and coconuts are almost always grated before squeezing from the meat fresh coconut milk, or using a variety of techniques to extract coconut oil. Meat and fish sometimes spoil before they can be sold at market due to a lack of refrigeration. Meat and kava mincing is also common. For cash crops, pulping coffee cherries to extract the coffee beans is a common manual task that also takes considerable effort.

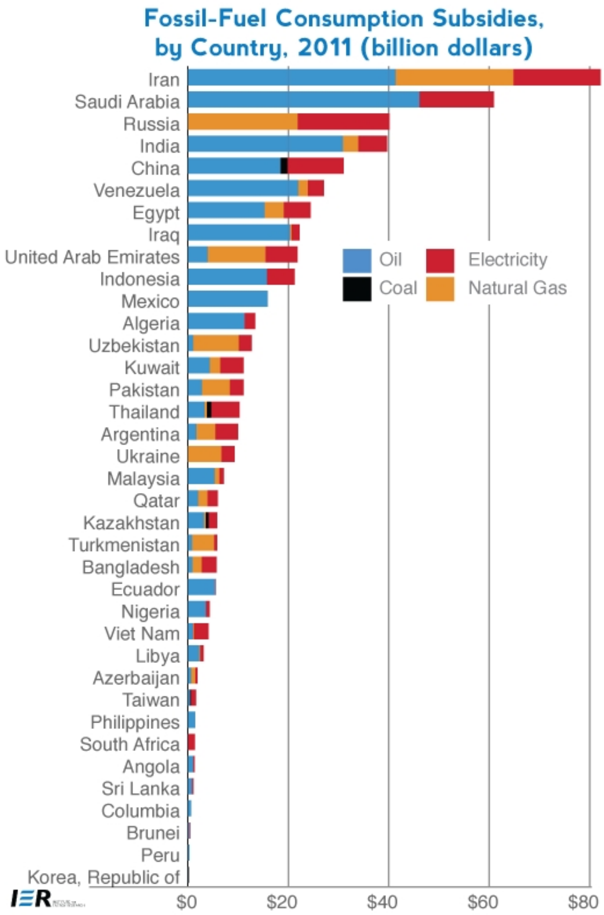
[7] http://press.anu.edu.au/wp-content/uploads/2011/05/part21.pdf
[8] http://aid.dfat.gov.au/Publications/Documents/solomon_study_vol3.pdf
[9] http://ageconsearch.umn.edu/bitstream/32666/1/wp58.pdf

An important part of the market analysis is also to describe what improvement solar agro-processing can bring to existing customers and markets. Agro-processing is currently undertaken using 3 primary sources of energy: grid or minigrid electricity that drive electric motors, diesel engines mechanically (not electrically) driving the processing machines, and manual processing by people, animals or hand-operated machinery. In offgrid unelectrified regions, diesel engines and manual processing dominates. In some markets like Indonesia, diesel fuel subsidies and high grid connection costs means that diesel powered engines run agro-processing machines even in electrified regions.

It is unknown globally how many diesel engines provide agro-processing services in rural villages, but assuming that 250 million offgrid households live in 5 million offgrid villages averaging 50 households per village, and diesel mill penetration is 10% of this market, up to 500,000 small-scale (<10kW) diesel mills may exist globally. In the Pacific, approximately 5 million people live offgrid in 1 million households and perhaps 20,000 villages, so a similar analysis may suggest 2000 diesel mills are sold annually throughout the Pacific (dominated by the country of greatest offgrid population, PNG). This estimate is only considered 'accurate' to an order of magnitude, and could be 500-5000 diesel mills in the Pacific.

Market data[10] indicates 50-100 million generator sets are exported from China each year worth $1.5 billion (averaging $92 each), and 57% are of less than 10 kW capacity. While China dominates the small generator market, other studies[11] suggest the global market to be as large a $12 billion. 25% of Chinese generators were exported to Africa and the Middle East, suggesting a volume of 10-20 million units, 10-20 times more than our estimate of agro-processing small diesel engines. This difference is likely to be accounted for by the fact most small portable generators are used in the construction and industrial industries, and even those used for stationary power are used for electricity, not running agricultural machinery. Many sales are made in urban areas as backup supply to failing grids, not just rural areas.

No diesel fuel subsidies exist in the focus market of the Pacific, but in other markets global (right), subsidies can offset the attractiveness of alternative renewable sources of power. India, Indonesia and Nigeria are three such examples of large developing country markets.




[10] http://www.uspowerco.com/articles/chinas_economic_boom_is_powering_industrial_g
[11] http://www.marketsize.com/blog/index.php/2012/11/12/portable-generators/

## 2.1.2 LAST-MILE MARKET ISSUES

While manual agro-processing equipment may reach to the deepest parts of rural markets, 2-10 kW diesel mills generally serve larger villages rather than the smallest. Most villages in developing countries are small, of less than 200 households (1000 people), as shown by the example in Figure 4 from India population statistics. A typical small diesel mill of 2-5kW can process 100-250 kg/hour of crop, and given each household consumes around 1kg/day of processed staple crops, one hour of operation per day can serve 100-250 households.

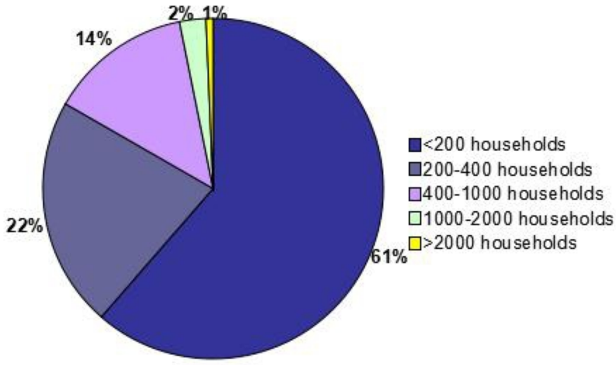



**Figure 4: Population distribution in rural villages**

As such, diesel agro-processing mills are rarely found in the smallest villages of 5-50 households. Thus, families from the smallest villages often have to travel to larger villages or the edge of the electricity grid to access agro-processing mills. These are often 1-10km distances, which may take 0.5-2 hours with free transport, or may cost $0.25-1.00 for a return trip using motorized transport. Processing a 25-50 kg bag of crop may cost $1, but so too may the cost of transport to and from the mill, effectively doubling the cost of agro-processing for small villages.

**Figure 5: Transporting crops by foot, bicycle, wheelbarrow and truck**

Thus, by providing smaller mills to small villages, a market gap can be met, and households can save transport costs. The needs of villages of 25-100 households would require 25-100 kg/day of crops to be processed by smaller solar-powered mills. Diesel mills of 2-5 kW process crops at 100-250 kg/hour, so smaller mills of 20-100 kg/hour will be well-sized for smaller villages. These would likely be have power consumption of 400W to 2kW. Noting that the smallest diesel engine/generator is 2kW capacity, this “micro solar mill” power bracket of 400-2000W is higher than the power humans can generate on manual machines[12] (50-150W by untrained people, up to 400W[13] by athletes).

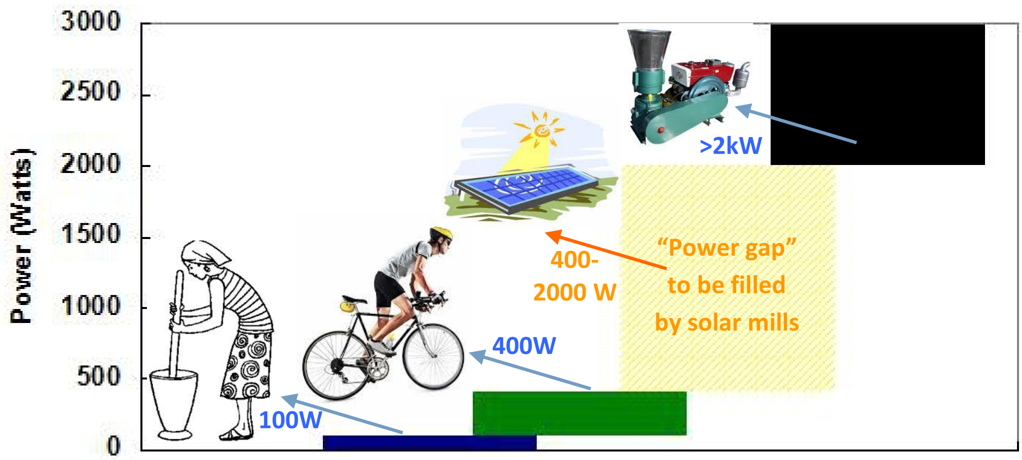



**Figure 6: 400-2000 W power “gap” between manual power and diesel mills that solar mills can fill**

Lastly, the diesel mill markets in the Pacific need to be briefly analyzed. Initial results from Papua New Guinea are already very promising, as the smallest 2-3kW diesel rice mills available retail for around $2200[14] and, if operated 1 hour per day, would consume around 350 litres of fuel per day, cost around $300/year, often higher. Thus, a minimal 2-4 year cost of ownership would be $2500-3500. Assuming 150 kg/hour of rice is processed per day, 2-4 years of operation would process 100-200 tonnes, giving a cost of milling service (before labour) of $12-35/tonne, or $0.012-0.035 per kg. In rural markets today, ungraded unsorted low quality rice may retail for $0.25-0.50/kg in the market and milling costs about 10% (paid in cash, or in kind as part of the crop milled, as noted in the field and in this FAO summary[15] of the rice business), so costs $0.025-0.05/kg, giving some margin for labour and other costs of the miller. Thus, to process a 25 kg bag of rice typically costs $1.

Cross-checks in other markets shows a Bangladesh[16] cost of milling of about $0.01-0.02/kg, which is likely to be lower than in the Pacific, and costs in Africa around $0.03/kg. It worth noting international export prices[17] for rice are around $0.40-0.50/kg and prices paid to Australian farmers are $0.25-0.30/kg[18], so a processing cost of $0.02-0.03/kg makes sense.

These 2-3kW diesel micro mills are generally oversized for their target markets because they can process 150-250 kg per hour but do not serve >100 households per day in remote areas (peri-urban mills often do and run for long hours, but remote mills do not). The mills are hence under-utilized, so it is concluded that the market shows excellent potential for a smaller (250-750W), slower (20-50 kg/hour) more highly-utilized rice mill to be sold in PNG and the Pacific for a similar 2-4 year cost of ownership ($2500-3500), particularly for smaller villages of 50 households or less, which is the

[12] http://en.wikipedia.org/wiki/Human_power
[13] http://cyclingtips.com.au/2009/07/just-how-good-are-these-guys/
[14] http://www.brighthopeworld.com/partnerships-print.asp?pid=128
[15] http://www.fao.org/docrep/x5427e/x5427e0i.htm
[16] http://www.mahabubhossain.com/pdf/Rice%20Mill%20Report.pdf
[17] http://www.indexmundi.com/commodities/?commodity=rice&months=60
[18] http://www.mmg.com.au/local-news/deniliquin/sunrice-announce-another-rice-price-boost-1.40898

median village size in PNG. Having one mill per village will also eliminate travel costs to reach a mill, which can effectively double the cost of milling ($1 to mill a 25 kg bag, and $1 to transport it to the mill and back).

The ex-China price of a 2-3kW diesel rice mill is around $500-600[19], so the factory-to-customer markup is over 300%, or a 75% margin, to reach a $2200 retail price. Markups of 100-200% (33-50% margins) for solar agro-processing machines are considered more aggressive yet sustainable, giving a target ex-China system cost for a micro solar rice mill of $2500-3500 / 100-200% = $1000-1750. It will be shown that such a package can be designed using off-the-shelf equipment, and thus, it may be possible to launch a solar rice mill in PNG at a similar 2-4 year cost of ownership of diesel mills, or 25-50% higher than the basic retail price (given there will be zero future fuel costs). The cost of the processed crop would be similar, assuming 3 hours per day of solar agro-processing 150 kg of crop at 50 kg/hour is analagous to processing in 1 hour at 150 kg/hour with a diesel mill. This could lead to a drastic market transformation in small-scale rice milling in the Pacific.

Other countries in the Pacific have similar price structures for diesel micro mills as PNG, characterized by high margins on imported machinery. In other countries outside the Pacific, a similar diesel rice mill may retail for closer to $1000 instead of $2000, and if diesel fuel is subsidized as it is in Indonesia and India, the 2-4 year cost of ownership drops from $2500-3500 to $1500-2000. This makes such markets far less suited to launching micro solar rice mills, other than where transport costs tend to double the basic cost of milled rice.

While the above detailed analysis of diesel mill prices was focused on rice mills, diesel-powered grinders for corn/maize/wheat flour are quite similar, though small diesel powered grinders may cost slightly less ($300-$500) than rice mills. Cassava is rarely processed in diesel mills, as it must be processed within 48 hours after harvest to avoid rotting, so is almost always manually processed. Yams are similarly locally processed, though are often roasted without significant processing. Similarly, potatoes, sweet potato and taro are often simply peeled and boiled, and do not need complex processing techniques to be edible. Plantains and bananas also fall into this category.

### 2.1.3 DESKTOP ANALYSIS OF MILLS

A detailed report on mill options has been prepared separately, for various target crops that are found in the Pacific. This includes manual mills that could be motorized, and powered mills of 2-3 kW capacity and lower. Low cost Asian-manufactured and top quality options are explored, with a focus on staple crop processing (flour grinders for cassava, wheat and grains; rice hulling; and coconut/taro grating). A short summary is included of cash crop processing.

An analysis framework will estimate the more cost-effective solutions in terms of lifetime cost of mills and their required power systems, in $ per kg processed over a 5-10 year life. For cheap low quality mills, this will include the need to replace mills, and for top quality mills, a 5-10 year life can be assumed that might help justify their higher initial cost.

A summary of these options is contained in Appendix A and is further discussed in section 2.3.

[19] http://wholesale.alibaba.com/wholesale/search?SearchText=diesel+rice+mill

### 2.1.4 STAKEHOLDER SURVEY

A survey of various stakeholders in Pacific agro-processing will be conducted. This may include villagers, importers, wholesalers and retailers, government departments and research institutes, civil society (NGOs) and fair trade experts, agribusiness and commodity traders, potential investors, equipment suppliers and manufacturers and others. The business parameters and risks will be explored to determine at what level solar and renewable agro-processing could be viable, including customer pricing for services, returns on investment, maximum loan periods and other risks.

## 2.2 BUSINESS DESIGN

Based on stakeholder feedback and desktop analysis, potentially viable business models will be formed. Overall, these will likely involve 1-5 year leasing of equipment to villagers on a pay-per-use basis, an assumption of expected utilization, and a price of service no higher than similar services offered by diesel mills.

As an example, a 25 kg bag of corn can be processed in 10 minutes by a 2-3kW diesel mill that consumes 1 litre per hour of fuel, worth $1/litre. Hence, the fuel cost of the service is approximately $0.17 of fuel, or $0.007 per kg. The overall charge for such a service by an entrepreneur is typically around $1.00, giving a $0.83/kg profit after fuel expenses. Such a mill in a remote village may only operate 1 hour per day to serve 6 customers a day and earn $6/day of which $1/day was paid for fuel.

In contrast a smaller, slower 1kW solar grinding mill would operate 2 hours per day, and require 500W of solar panels to generate sufficient energy to provide the same service. Assuming the actual mills cost a similar amount, $1/day of fuel cost is available to pay off 500W of solar panels and a DC electric motor. These may have an installed cost of $1000-2000, so require 1000-2000 days to pay off, or 3-6 years. The lower end of this range with within the realm of feasibility. Noting that 2kWh are sold per day for $1, the cost of energy supplied would be $0.50/kWh.

Another example is a coconut grating machine. In Vanuatu, coconuts are cost approximately $0.20-0.40/nut in the local market, which are then taken home to be shredded so coconut milk can be made for the daily meal. Local entrepreneurs believe a bag of freshly shredded coconut that saves a household the time and effort of shredding could be sold for $0.30-0.40/nut,giving a $0.10/nut profit for the entrepreneur. If 20% of the profit ($0.02/nut) is given for use of the solar grating machine, and 10 nuts per day are sold to generate $0.20/day of income, then $0.10/day would pay for the solar panels and $0.10/day pays for the mill, or $30/year. Such a mill as this may require 1 hour of use to process 10 nuts, of a 200W electric grater (costing $50-100) powered by an 80Wp solar panel. This mill may have an installed cost of $200-400, so would take 7-15 years to pay off. If used for 4 hours per day using 200-300W of solar panel that costs $300-400, annual mill income may rise to $120/day, and the mill cost of $500 may be paid off in 4-5 years. If the profit share rises to 30-40% of gross profit, this can drop further to 2-3 years.

Noting that 0.2kWh of energy is sold per day for $0.10 that is paid towards the panel cost, the cost of energy supplied would be $0.50/kWh, which is similar to the grinding mill example and similar to a diesel mill ($1/litre and 2-3 kWh/litre = $0.33-0.50/kWh). However, if a 2-3kW diesel generator supplied the power for 1 hour for a 200W grating machine, it would consume 1 litre of fuel costing $1 of fuel, so a 80-300Wp solar mill at $0.10-0.40/hour is far cheaper per hour than a diesel mill at 20% gross profit share, and still cheaper if this profit share is doubled.

Therefore, it is likely that the most viable solar agro-processing machines will be those of considerably lower power and energy consumption than the smallest diesel mill available (2 kW), but at a level higher than that which humans can deliver for an hour or more (about 100 watts), giving a "sweet spot" range of 200-1000W where solar mills should be used.

Lastly, there is a case of time-saving, where mills are used in situations where cash savings on diesel fuel or cash earnings on cash crops are not possible, such as saving time processing staple foods for daily meals. A case study could be a taro grating machine, which reduces processing time from 40 minutes per day to 10 minutes, saving 30 minutes per day. Many women are involved in basket weaving in rural areas, as an example, and these take 5-10 hours of work per basket, and sell for approximately $10 each. Thus, productive labour could be valued at $1-2/hour, and a taro-grating machine is thus creating $0.50-1.00 of potential productive time per day. To encourage this conversion of time saved to extra income generated, mill leases could be paid in village exports, rather than cash, such as locally woven baskets or cash crops or other items, which are then sold in local or international markets (ie. a barter system).

A 500W vegetable grater can process 2kg of crop per household per day at a rate of 40 kg/hour, or 3 minutes of operation, so 20 households could be served daily per hour of operation, creating $10-20 of productivity across the 20 households, or $0.50-1.00/house/day. If $0.10/house/day is charged to these 20 households, $2/day of income would allow $1/day to pay off 150-200W of solar panels and $1/day to pay off the grating mill. Noting that 0.7kWh of energy is sold per day for $1 that is paid towards the panel cost, the cost of energy supplied would be $1.40/kWh, midway between the diesel displacing rice mill and the value-adding coconut grater.

At an estimated installed cost of $700-1000 for the whole mill, the payback period may be 2-3 years when the households only spend 10-20% of saved time making products to pay off the mill. However, if the 20 households who save 10 hours/day collectively spend 100% of their saved time producing a woven basket per day as payment that is worth $10, then mill could be paid off with 70-100 baskets in as little as 70-100 days. The 70-100 baskets, or equivalent village export, would then be sold in local or international markets. This bartering mode of payment perhaps offers the most promise. That said, payment for service will also be possible, at approximately $0.10/day or $0.05-0.10/kg.

A comparison of all business models can then be made to determine which is the most viable.

## 2.3 TECHNICAL DESIGN

### 2.3.1 MILL TESTING

As noted in previous sections, the focus of the project is more on staple foods than cash crops, and is limited mostly to those that require processing before being edible, as opposed to staple foods that are not processed much before eating. This focus could be termed as "necessary agro-processing", without which villagers may very well starve if it is not undertaken, either manually or by machines.

Thus, the focus technologies of the solar agro-processing project includes

1) Cassava and yam grating
2) Rice hulling
3) Rice (and other) winnowing
4) Corn/maize/cereal threshing
5) Corn/maize/cereal flour grinding
6) Coconut scraping

and to a lesser extent, these non-staple processes:
7) Coconut oil expelling
8) Herb/vegetable chopping
9) Meat and kava mincing
10) Food refrigeration

Appendix A summarizes these ten agricultural processes, including current manual methods, diesel-powered solutions where available, and a range of small and larger solar-powered electrical potential solutions, sourced from internet research of possible global suppliers. Manual methods tend to have a processing rate of 1-10 kg/hour, while diesel-powered solutions have a rate of 100-500 kg/hr, and thus can process 50-100 times as much per hour of use. With an average of 2 hours/day diesel mill use over a full year (which can be much higher during harvest season), 100-200 households are typically served by a 2-3 kW diesel mill.

In contrast, small solar mills process 10-50 kg/hour using 150-500W of electrical power, while larger solar mills process 100-500 kg/hr like a diesel mill, and uses 1.1-2.2 kW of electrical power. The larger mills are designed to directly match the diesel mill capabilities, while the smaller 150-500W solar mills seek to fill the "power gap" which is more power than manual labour can deliver (<200W) and less than a typical diesel mill (>2000W).

Of the above list, the following 10 solar mill technologies have been tested using an inverter to convert DC battery power to conventional AC power:

A) a 150W low speed vegetable/cassava grater

B) a 400W high speed vegetable/cassava grater

C) a 500W rice mill for hulling with winnowing, to produce brown rice

D) a 750W (1 hp) rice mill for hulling with winnowing and polishing, to produce white rice

E) a 1.5 kW (2 hp) rice mill for hulling with winnowing and polishing, to produce white rice

F) a 250W (1/3 hp) wet grinder for soaked maize typically used in central/south America

G) a 375W (1/2 hp) coarse flour grinder for maize (dry or wet)

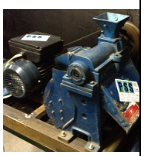
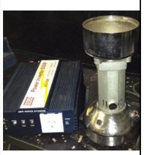
H) a 1.1 kW fine flour grinder for maize (dry only)

I) a 180W (1/4 hp) coconut scraper

J) a 180W herb/vegetable chopping machine

A clamp multimeter was used to measure the high currents being drawn from the battery during these tests. Results were as expected from the Power = Volts x Current basic law, such that current (Amps) will be power divided by the 12V battery voltage. The following results were obtained.

**Table 4: Test results of current drawn from 12V battery via inverter**

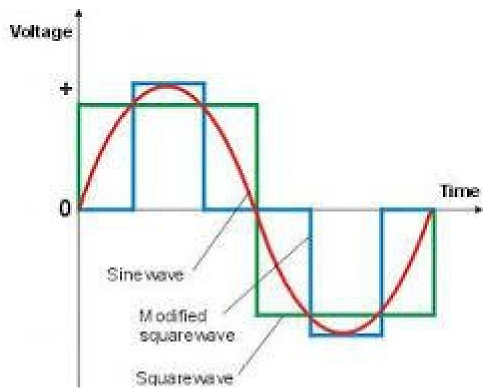
| | Descriptions | No load Amps | Loaded Amps | Startup Amps |
|---|---|---|---|---|
|  | 150W rotary drum vegetable/cassava grater | 15 | 18 | 30 |
|  | 400W cassava grater using a manual flat-blade Mouli and a 2000 rpm drill | 0 (uses trigger to control speed) | 0-35 (usually 20) | 5-35 (can use trigger to slowly start) |
|  | a 500W triple rubber roller brown rice mill (hulling+winnowing) | 35 | 40 | 100 |
|  | a 750W steel worm white rice mill (hulling+winnowing+polishing) | 50 | 60 | 120 |
|  | 1.5 kW white rice mill with hulling, winnowing and polishing | 70 | 80 | 160 |
|  | 250W Nixtamatic stone grinder for wet, soaked maize | 18 | 20 | 40 |
|  | 375W stone grinder for coarse flour (dry or wet) | 25 | 30 | 100 |
|  | 1.1 kW Wondermill impact grinder for fine flour | 55 | 75 | 120 |
|  | 180W coconut scraper | 17 | 20 | 60 |
|  | 180W herb/vegetable chopper | 19 | 20 | 40 |

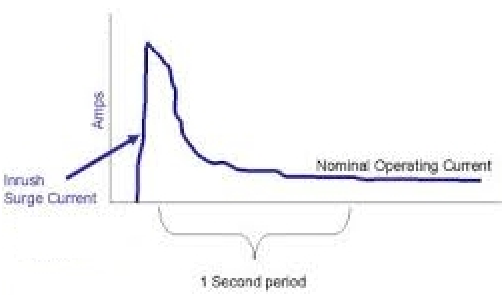
To avoid the use, cost and system complexity invert, some of these products could have the AC motor removed and replaced with a DC motor, which can run directly from the battery. However, the project period was not long enough to re-engineer these products to run from a DC motor, and the test results have been limited to procurement of five 12-24V 200-500W DC motors. These clearly operated from a battery as advertised, and in the months following the end of the project (Oct-Dec 2014) several mills will have these DC motors connected, specifically aiming at the coconut scraper, brown rice mill and cassava grater.

### 2.3.2 MOTOR STARTING

Based on mill performance data, the solar systems can be designed. Two main system designs are the core focus - using 120-240V AC mills with an inverter, or 12-48V DC systems without an inverter.

Inverters can come in two major forms, pure sine wave and modified sine wave. The latter is a poorer quality of power, but is a cheaper inverter. Guides[20] written about the difference between these types of inverter suggest that resistive and universal motors will be unaffected. Inductive loads can be affected, such as modern sewing machines, timers, microwave ovens, battery chargers, dimmer switches, digital clocks, variable speed motors like fans, sound equipment, TVs, videos, printers and some fluorescent lamps. Given most products tested were fixed speed motors, it was considered acceptable to use a modified sine wave inverter.




The second major consideration is the surge current taken to start the motor, which can be 2-10 times the running current of the motor after it has started. The multimeter used gave an indication of surge currents (Table 4), but more advanced equipment would be needed to precisely characterize the surge of each products' motor (also known as locked rotor current). The precise calculations are explored further in Appendix B, but typically it is wise to size the inverter 3-5 times higher than the running power of the appliance. Inverters can often withstand surge currents 1.5-2 times their rating, which can help. Thus, a 2400W modified sine wave inverter was used for starting the appliances, which could take up to 200 Amps from a 12V battery. Smaller inverters were also periodically tested, and some motors were found to start far more easily from small inverters compared to others, indicating lower surge current requirements.

Motor control devices also exist to reduce surge currents, called "soft starters". However, these generally cost similar per watt as an inverter, so any savings made reducing the size of inverter is used to purchase the soft starter, particularly for small power levels. Therefore, these solutions were

[20] http://www.rpc.com.au/pdf/sine_&_square_wave_electricity.pdf

not tested, as the provided no commercial advantage. Typically, a 750-2500W inverter is recommended for the small solar mills of 150-500W, and 2500-5000W inverters for the larger 1.1-2.2kW mills. These typically cost $50-500 and $500-1500 respectively[21], though far higher costs of $1500-5000 are possible for the top quality inverters, such as Outback inverters. In testing, mid-range inverters were used costing $300-500 for 2400W, and largely worked satisfactorily during initial tests. Thus, a costing of $0.20/watt is considered rational, though top quality inverter cost as much as $1/watt.

For the case of designing without inverters, where DC motors are used instead of AC motors, similar surge currents exist but can be drawn directly from a battery, similar to the high surge currents drawn from a battery when starting a car. Inverters are not longer required, removing a cost and a potential point of failure. DC motors may be more expensive than AC motors, but the extra cost is likely considerably lower than the cost of adding an oversized inverter. With the boom in electric vehicles and bikes, more quality suppliers are available than every before, and at competitive prices. DC motors at 12V generally cannot exceed 200W of power, while 24V motors are typically used for applications up to 500-750W, 36-48V motors used for 1-3kW applications and 72V or higher used for 3-10kW applications. Therefore, operating currents are typically kept at 20-40 Amps - currents up to 100 Amps can use off-the-shelf components, but if currents climb to 100-300 Amps, specialist equipment is required which can cost significantly more.

### 2.3.3 SOLAR SYSTEM DESIGN FOR SOLAR MILLS

In Appendix A, the size of solar panel required for one hour of operation of the 10 various solar mills is given. This typically ranges from 80Wp to 200Wp for 150-500W for smaller solar mills that fillt he "power gap" for small villages of 10-50 households, and 500-1000Wp for larger 1.1-2.2 kW solar mills that compete more directly with diesel mills in larger villages of 50-200 households.

The rationale for this is simple. As shown in Table 4, 20-40Amps is required for 150-500W mils, so this energy must come from the solar panel. For one hour of operation, 20-40Ah of energy is required, and solar energy in target markets is generally 4-5 hours of sun, so 5-10 Amps is required at minimum from the solar panel to fill the battery over 4-5 hours with 20-40 Ah of energy. Noting that solar panels charge batteries using power at 16-18Vmp, the power required is at least 80-180W. It may be necessary to increase the solar panels to allow for system inefficiency and non-utilized solar energy if the battery used is very small. A simple rule of thumb is that for one hour of power for the mill, half the solar panel wattage is required of the mill's power consumption (eg. a 180W mill needs a 90Wp panel for 1 hour of power).

Similarly, the larger solar mills using a 1.1-2.2 kW mill will require at least a 500-1000 Wp solar panel to allow 1 hour of runtime for the mill.

Installing less solar power than the mill power is only possible if batteries are used to supply the mill power - a different example is a battery-free "direct drive" system where the solar power is at least

[21] http://www.amazon.com/s/ref=nb_sb_noss?url=search-alias%3Daps&field-keywords=1500W+inverter&rh=i%3Aaps%2Ck%3A1500W+inverter

as much as the mill power, such as that used by www.solarmilling.com (which may also use an inverter to run the mill's AC motor). This "direct-drive" design is similar to a solar water pump. A disadvantage of a battery-free system is that if there is not enough solar power, the mill will not work. However, batteries are more expensive than solar panels, and have a shorter life, so it is not optimal to store 100% of the solar power either (unless milling is a task usually not undertaken in the daytime, such as in some very hot parts of northern India).

To allow for short-term interruptions in solar power such as a large cloud or a short intense downpour of rain, it is commended to use 30-60 minutes of energy storage from a battery. The battery must also be big enough to supply enough "cold cranking amps" to start the mill during startup. For example, a 12V 10Ah AGM battery can provide 150-200 Amps of starting current, sufficient to start a 20A-40A 12V motor (240W-480W) and run it for 10-20 minutes before reaching a low voltage cutoff state. Thus, to provide 30 minutes of runtime for small solar mills (180-500W), a recommended 12V battery size would be 20-40Ah. To provide the same for large solar mills (1.1-2.2 kW), a recommended 12V battery size would be 100-200Ah, though probably arranged as a 24V-48V battery pack of lower Ah capacity.

When inverters are not used to run an AC motor, DC motors must be used. Market research suggests that 12-18V motors are available up to around 200W, while 24V motors are available up to 500-750W, and for loads of 0.75-2kW, 36-48V motors are common. Higher voltage motors are used for even higher power applications above 2kW, which is beyond the scope of this study. Motors used for electric vehicles are widely available, from light uses like scooters, medium power for bicycles and high power for golf carts, go-karts, forklifts, airport vehicles, electric motorbikes and electric cars. Given most mills will run for long periods of time, those with fans to assist cooling can be a better choice. A detailed analysis of brushed, brushless or series-wound motors is beyond the scope of this report, but the advantages and disadvantages of various motor types should be considered before using them in mills, as well as control systems and post-installation servicing.

### 2.3.4 MONITORING SYSTEM DESIGN

To allow systems to be monitored once deployed to the field, remote monitoring and control systems may need to be added to the design, rather than relying on manual methods of monitoring. Understanding how much energy is generated by solar panels, and how much of this energy is consumed by the mill (or other end uses). Current pay-as-you-go technologies that are making leasing of solar home lighting systems more commercially attractive, which measure 1-2 Amps or less, cannot directly measure the high currents of 20-100 Amps that are used in solar agro-processing systems. Other solutions are required to measure the energy, and transmit this data to key stakeholders. Off-the-shelf solutions is the main focus of this part of the design, rather than fundamental research and design of new circuits, given the limited budget and time for the project.

Where possible, the aim will be to deliver real-time data of 10 minute usage or better to an internet portal, so that project investors can easily see both power generation from the solar panels, and power consumption by the mill users, and hence have a good understanding of utilization. Such data can also drive an accounting and billing system.

## 2.4 OTHER ISSUES

Reductions in $CO_2$ and black carbon emissions will be estimated in this section. However, given the short-term nature of the project, this is not a major aim for the project, and given that earlier analysis indicates that head-to-head competition with diesel mills is the least commercially attractive, revenue model, reduction in manual labour may be a more significant outcome. Unexpected qualitative impacts can also be summarized in this section.

# 3 PROJECT RESULTS

To date, two mills have been installed at a milling centre near Port Vila, Vanuatu, and a further four mills and a refrigerator have been installed near Lae, Papua New Guinea. This total of 6 mills installed far exceeds the project target of 2 mills, and a further 1-2 mills may be installed if budgets allow after the completion of this progress report. At each mill, a record of customers will be kept to log whether a total of 50 customers benefit from these mills, as per the project target. The upcoming monitoring and evaluation visit will determine if this goal is likely to be met by the project end date.

## 3.1 INSTALLATION 1 AND BENEFICIARIES

### 3.1.1 MILLING CENTRE 1 LOCATION

The first field deployment of solar powered mills has been undertaken at the office of our importing partner, ACTIV Association, located on the outskirts of the capital city of Vanuatu, Port Vila. While it been considered to deploy the mills to deeper rural areas, this has not been pursued for two reasons - the first is that communications becomes far poorer in remote areas, so feedback of issues will not be as reliable, and the second is that Port Vila has been found to offer accessible markets for mill output that would not necessarily be available as easily near remote villages on other islands. ACTIV is also a buyer of fair trade value-added produce from farmers, so has a more specific reason to be interested in the success of solar agro-processing than an average solar equipment importer. During early July, two mills were installed at ACTIV's training centre outside Port Vila.

**Figure 7 : ACTIV training Centre outside Port Vila, Vanuatu**

### 3.1.2 COCONUT GRATER

The first mill installed was a coconut grating machine. In the vast majority of households in Vanuatu, a coconut is grated each evening so that coconut milk can be extracted for use in the daily meals. Grating coconuts is strenuous work, and grating one coconut takes 5-10 minutes of manual labour using a sharp toothed blade typically fixed on a stool to keep it secured in place during use. Fresh food markets across the Pacific often have several women selling coconuts (Figure 4), mostly to other women who prepare the meal daily at home. Greg Denn has noted the use of electric graters in use in southern Thailand where similar markets exist, such that women can buy a freshly grated coconut instead of having to grate it themselves. Electric coconut graters (that use 230V AC mains electricity, not designed DC electricity from solar panels or batteries) are available in the Port Vila market, retailing at $60-120.

**Figure 8: Coconuts on sale in Vanuatu for Vt 200 for 10 (approximately US$0.20 each)**

A coconut grater consumes 180W and a coconut can be grated slightly faster on the mill than manually, but not significantly so (and in some regions of the Pacific where electric graters are not used, manual processing may be faster until local skills are attained). However, continued manual grating for hours to process 10-100 nuts per day per worker would require significant labour and effort and thus require an electric mill, whereas processing 1-10 nuts would arguably be simpler to do manually. Hence, as a minimum viable business, one machine may be expected to be used to grate 10 nuts in 1 hour of use. Given 4 hours of solar energy to supply 180W for one hour, a 60W solar panel may be required (allowing for some system inefficiency). The first mill has been set up with a 80Wp panel to allow for some conservatism. This can be expanded if demand for the mill is higher. Given that no coconut grater exists on the market at this point runs from DC, an inverter has been added to convert the DC battery energy to AC, so a 'normal' grater can be used. Motors take significant surge currents during startup, so a 1000W inverter was used, considerably larger than 180W load.

**Figure 9: Coconut grating mill and Wondermill grinder set up with battery and inverter**

### 3.1.3 FLOUR GRINDER

The second mill installed in the ACTIV training centre was a flour grinding mill. This was a 1.2kW 40kg per hour Wondermill, which can dry-grind many different crops (www.willitgrind.com). Notable exceptions include peanuts and coffee, which have considerable oil content and "gum up" the machine - it is more suited to wheat, corn and other grains, plus some spices. While it is expected that multiple uses can be made of this mill, the primary target is to process hand-pounded sun-dried cassava into flour fine enough to be used as a 5-10% substitute in imported wheat flour, as is currently happening in other markets such as Nigeria and Ghana. Future development of this project will require more sophisticated processing techniques to ensure cyanide and aflatoxin levels do not exceed food safety regulations, but given that $10-20 million of flour is imported per year to Vanuatu, a 5-10% substitution program could generate a business worth $1 million of revenue, selling 2000 tonnes/year or 10 tonnes/day of high quality cassava flour (HQCF). One Wondermill can process 150-200 kg/day, so this could represent potential for 50 distributed Wondermills in regions of high cassava production, or fewer larger mills. However, cassava must be processed within 4 hours of being dug up, so it is important to process the crop as close as possible to source as possible.

Given the flour mill takes 1 hour to process 40 kg, and households may use 1kg per day for consumption (or sometimes for animal feed), then 1 hour of processing can serve up to 40 households. Using 4 hours of sunshine per day, approximately 300-400Wp of solar panels would be required for this hour of operation. This equates to approximately 10Wp of solar power required to process a staple crop for household consumption. The preliminary installation has included just an

80Wp panel until utilization information is gathered to see if the mill is being used. The 2000W inverter has been able to operate this mills' motor without issues with startup currents.

## 3.2 INSTALLATION 2 AND BENEFICIARIES

### 3.2.1 MILLING CENTRE 2 LOCATION

The second milling centre has been set up outside the 2nd largest city of Papua New Guinea, Lae. The Malahang Industrial Reserve outside Lae contains the main office of a leading specialist in micro agro-processing in PNG - Project Support Services (PSS), managed by Mr Gregory Denn. Lae is surrounded by settlements (urban slums) which are not yet connected to the main electricity grid, and furthermore, villages near Lae often pass Malahang on the way into town. There are also many other industrial companies in this compound, and hence employers, resulting in considerable traffic.


**Figure 10: Milling centre location at Malahang Industrial Area, near Lae, Papua New Guinea**

This has resulted in a small market forming directly outside the gate of Malahang mostly for workers of the compound, and most of these workers live in off-grid villages and settlements around Lae. This small informal market, which has no direct access to electricity, is an excellent test area for the solar mills to be operated at daily, with access to offgrid customers, but with the daily security of the PSS office to secure the mills after operation. PSS's staff are also from offgrid settlements, and will be selling the produce around their homes that they travel to each day.

Four mills and a refrigerator have been installed by PSS at the Malahang site near Lae. These are described in the following sections.

### 3.2.2 COCONUT GRATER

The first mill installed has been a coconut grater, given this is often a daily need in the diets of the households of the area, similar to the situation in Vanuatu. A similar market as described in Vanuatu is expected to be developed, where 30-50% more revenue per nut can be charged for a grated coconut compared to an normal coconut, and an 80Wp panel can power the 180W mill for at least one hour of operation to process approximately 10 nuts, generating approximately $1/day of income to help pay off the mill.

**Figure 11: Coconut grating mill installed at Malahang - inverter and battery shown at right**

#### 3.2.3 RICE HULLING MILL

A 1kW rice mill has been installed at Malahang, using a belt drive from an electric motor to run the mill. The electric motor runs from a battery and inverter system, similar to other mills installed.

**Figure 12: Solar powered electric rice hulling mill**

Unlike Vanuatu where little to no rice is grown locally and all rice is imported, PNG has a growing industry of locally grown rice that is an attempt to displace imported rice. The National Agriculture Research Institute (NARI) and a major distributor (Trukai) have shown strong interest in the concept of a solar rice mill. Diesel rice mills of minimum capacity of 200 kg/hour are sold at approximately $3000 in the local market with very high profit margins, and similar mills in Asia might sell for just $500-1000. The fuel operating cost is at least $1-3/day to run, or $500-1000/year, and often more when mills are run more than 1 hour per day. Therefore, a 5-year total cost of ownership can easily total $5000-8000.

In contrast, a 40-80 kg/hour slower solar rice mill may possibly be installed for as little as $3000, giving an upfront similar price, but zero operational (fuel) cost. While this mill may be slower, it is appropriately sized for a village of 40-80 households, which is the typical size of a PNG village. Most diesel mills in PNG are oversized for their application, and are installed primarily to win votes my local politicians.

#### 3.2.4 FLOUR AND FEED GRINDER

The following diagram shows a 1kW hammer mill, which is used for grinding flour and creating feed for animals. It can be seen to be considerably larger and heavier than the Wondermill grinder, and processes 200 kg/hour rather than 40 kg/hour. For a higher market volume such as Malahang, this is an appropriately sized unit.

**Figure 13: Solar powered grinding mill for flour and chicken feed preparation**

### 3.2.5 HERB CHOPPER/GRINDER

A micro chopper/grinder has also been added to the system, to process local ginger and chilli, and may also be used for small amounts of local peanut butter and coffee grinding for local use. This may also be used for kava, a popular root for chewing in the Pacific, but a motorized meat mincer may be a preferred method of kava processing, given that manual meat mincers are used for now.


**Figure 14: Herb and spice chopping machine**

### 3.2.6 REFRIGERATION

Solar refrigeration options have been investigated at a desktop level, but none have been tested or installed during the project. Desktop analysis indicates that with the cost of solar panels reducing drastically in recent times, the much higher costs of DC solar refrigeration is possibly no longer rational compared to purchasing a normal energy efficient refrigerator and running it from a small inverter. Such solutions could cost $1000-2000, compared to $2000-8000 for solar DC refrigerators. Upright refrigerators should be avoided where possible, s these tend to be less efficient than chest-style refrigeration.

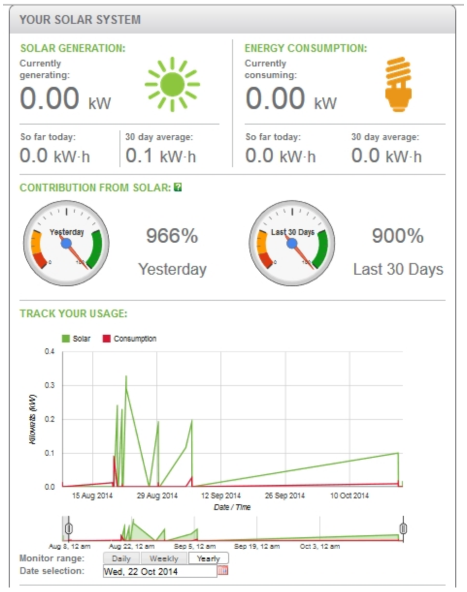
The most cost-effective, energy efficient option is likely a conventional chest freezer converted to a refrigerator, running from 80-160W of solar and using 100-200 kWh/year (a average 24-hour load of 10-20W). Small (20-200L) units should be avoided - sharing a larger 200-400L unit is optimal.

## 3.3 SYSTEM MONITORING

To increase understanding of system performance, part of the project budget has been assigned to purchasing monitoring and control equipment so as to know how much energy has been generated daily, and how much of this energy has been consumed. Two different monitors to date have been used - one that measures AC power, and one that measures DC power. Assuming a cost for a solar agro-processing mill is likely to be $500-$5000 for 200W-2000W solutions that serve 10-100 households at a cost of about $50/house, and solar lighting systems may be added to this at a cost of $100-200/household, the cost of monitoring needs to rationally be less than about 10% of the overall cost, so no more than $15-25/household, and preferably lower. This is similar to the cost of GSM technology in pay-as-you-go solar home systems (though some technologies such as Angaza may be closer to $5-10/household).

Thus, for a 10-household project that might use a 200-500W mill, a rational budget for monitoring and control is $150-250, while $1500-2500 is possible for a 100-household project.

### 3.3.1 EMPOWER MONITORING SYSTEM




A reasonably priced (AU$264 retail) Empower system from Energy Matters in Australia was procured as a rapid example solution for real-time monitoring, viewable at www.energymatters.com.au Should the client wish to log in to see the data themselves on the online portal (right), the login name and password can be shared on request.

This system uses a main communication hub that is ethernet-connected to the internet and to a power supply, which communicates wirelessly to two current sensors via bluetooth. These sensor modules include hall sensors that are placed over the live wire of an AC-connected electrical equipment such as a mill (though the intent is that this is placed on the live wire of a 1-5kW grid-connected solar panel array + microinverter, or the main house load wire). Two mills are now being monitored in ACTIV's main training centre on the outskirts of Vanuatu - a coconut grater and a cassava/vegetable grater. The bluetooth sensors operated successfully over a 25m distance to the communication hub.

One disadvantage of this system is the ethernet internet connection required for communication of the data, which would not be available in a remote area. Also, it is designed for AC power, not DC, so must be placed downstream of the inverter, and thus can only measure AC loads, and cannot measure DC current flows into the battery from the solar panel, not could it measure current in a system without an inverter. However, supply chain research indicates such equipment can be sourced from China, and at lower prices than this retail price ($50-150, depending on how many sensors are attached). 8-12 sensor versions are available which could measure power at 8-12 households, allowing a $150 cost to be spread over a group of households, at $15-20/house, which is in line with our budget for system monitoring.

### 3.3.2 TREK TRANSPONDER MONITORING SYSTEM


One additional solution was sourced from Australia that solved some of the issues with the AC monitor from Energy Matters. The Trek Transponder system uses a sim card to report back the data it is measuring, and thus can be placed in remote regions. Secondly, it is designed to measure DC current flows instead of AC, so is well suited to measuring both solar panel input current and load current. At AU$340, these were a similar price to the Energy Matters monitor. No hall sensors were used - the system required some moderately complicated hard-wired connections to be made, and no wireless communication is involved with the current sensors.

The main disadvantage of this system is that data collection was only possible when an SMS message was sent to the system. Thus, the real-time 10-minute averages that the Energy Matters system logs as long as it is operational was not directly possible. The supplier claimed such systems had been set up, but this appeared to involve considerable extra cost and effort, so was not readily available. Due to the fact spot data was not practical for monitoring, this monitor was only lab-tested and not deployed into the field. With further funding, it may be possible to set up this ongoing data acquisition, but the better path forward is likely to be procuring a similar GSM-enabled monitor from China, at a lower cost, that is already set up to regularly log data.

## 3.4 ENTREPRENEUR TRAININGS

During installation, a training session was held for local entrepreneurs to help them understand how to run the mill technically, and how the business aspects may addressed. Trainings were held at two locations - one on the outskirts of Port Vila, Vanuatu and a second on the outskirts of Lae, Papua New Guinea.

### 3.4.1 TRAININGS AT SITE 1

At the Port Vila milling centre, two local entrepreneurs from nearby villages were trained on establishing a coconut grating business, and potentially a cassava flour grinding business. These would not be full time occupations, but a market opportunity to value-add to their existing produce and try to sell their crops for higher price in the Port Vila markets.

**Figure 15: Two entrepreneurs trained from villages near Port Vila**

In addition, two of ACTIV's staff were trained on how to install the solar milling machines, so that these skills could be used outside the milling centre in the future, in rural villages in outer islands in the future.

### 3.4.2 TRAININGS AT SITE 2

The staff of our field partner, Project Support Services, have been the entrepreneurs trained to sell the outputs of the solar-powered agro-processing machinery in the second milling centre at Malahang Industrial Reserve, just outside Lae. All staff live in settlements around Lae that have no access to electricity, and are surrounded by neighbours in a similar energy deficient situation. PSS has been manufacturing micro-scale agro-processing machines for almost 15 years, so supply of machinery is relatively simple, a wide range is available, and the staff have in-depth knowledge of the construction and maintenance of such mills.

However, PSS and its staff have not ever deliberately started a strategy of using the machines they sell to product value-added produce, so this was the focus on the training - to understand the cost of crops provided, the sale price of the processed crop, the profit to be made and the profit share payable for use of the mill. Such payments can be made via wage deduction by the manager of PSS, and would only be on pay-per-use, so no wage reduction would occur if the mills were not used by staff to make a profit. The staff have committed to buy their own family's food needs from the mills, and will sell in households near to their own to build up more business. Each staff also has a home village many miles outside of Lae, and in the future, the mills can be deployed to their home village where PSS staff can train their family members on how to operate the mill. Clockwise from top left, they are Henson Sedrik, Milan Gelakaupa, Albert Mun and Alan Mambi.

**Figure 16: Four entrepreneurs (PSS staff) trained from offgrid settlements near Lae, PNG**

To complement this grassroots strategy, marketing inroads are being made to major customers such as the National Agricultural Research Centre (NARI), Trukai (the biggest rice importer in the country) and wholesale/hardware chains such as Brian Bell, Agmark and others. However, despite that it is highly likely that sales of dozens of solar mills could be secured with months of a launch, working capital for expected demand is insufficient to stock enough product, so a go-slow strategy is currently in place with these larger customers.

## 3.5 INVESTOR MOBILIZATION

IRENA's role in the Pacific is not to finance the purchase, freight or installation of hardware, but to provide technical assistance in the form of training and capacity building of entrepreneurs, supply chain partners and other stakeholders such as government departments, donors, civil society, investors and others. As such, the cost of purchasing the mills and installing them falls upon VIA and its investor network to finance. VIA has reached out to its network to gauge interest in investing in offgrid solar agro-processing, and has received a warm but cautious response, not least because the technology is relatively untried and has less proven market acceptance than offgrid solar lighting. The aim of the project was to mobilize $10,000 of investment for at least 2 solar mills.

Sources of investment have been discussed in detail in a previous IRENA capacity building project for offgrid lighting in the Pacific, and will not be replicated here. In short, our primary sources for capital for the project, given the small amount to be raised in a relatively short time period (2-3 months), was individual investors (angels and crowdfunding platforms) who are investing their own funds, rather than impact investors or fund managers who invest other people's money. The latter often have minimum deal sizes of $100,000 to $1 million, and take 6-18 months to process a deal, while individuals and crowdfunders typically process a deal in 3-6 months.

A previous investor in Vanuatu lighting projects has expressed intent to invest so long as the project is limited to PNG and Vanuatu - the Rotary Club of Melbourne. Two more angel investors have also been secured to invest up to $10,000 as well, for any global application of the technology in any developing country - the first is an angel investor who lives in Arlington, Texas, USA and is also associated with Rotary, and has a strong regional interest in Honduras and Liberia. The second is the managing Director of PSS, our PNG field partner, who can put to work some working capital of PSS to help develop the market in the short term. Lastly, VIA is also a field partner of www.Kiva.org, which has recently expanded it's line of credit with VIA from $20,000 to $50,0000 before considering higher levels later this year of $200,000-400,000. The strategy is to build the project using the angel/Rotary funding, and then to refinance the project on Kiva to obtain interest-free capital for the long-term loan (and to spread any risk of default over hundreds of investors instead of just one).

From the project start date of May 2014, PSS was able to make funds available as-needed for project implementation. Rather than formalizing a loan, PSS will purchase this equipment and cover installation costs, then when other investors' loan capital is secured, these funds can be reimbursed from this loan capital that VIA. After negotiations that took longer than expected a closing of the $10,000 target is expected from Rotary Melbourne by 15th August 2014, well before the closing date of the project (30th Sep 2014). The first loan that Rotary Melbourne invested with VIA for a similar project in Vanuatu, but for solar offgrid lighting instead of agro-processing, was a 3.5 year loan (42 months) at 10% p.a. In contrast, this loan is for 5 years at 5% p.a. Interest, given that the development of the solar agro-processing systems are less mature than solar lighting systems. It is expected that, once PSS and Rotary funds have helped to finance construction of the project, and some months of data have been collected to prove up a consistent business for the entrepreneurs, the project will launch on Kiva in late 2014 for 0% interest crowdfunding, and Rotary Melbourne will be repaid from these funds from early 2015. Kickstarter may also be an alternative crowdfunding website for raising the long-term lending capital.

## 3.6 DISSEMINATION WORKSHOPS

As part of the overall contract, two local workshops were held in Papua New Guinea and Vanuatu (1 each) during monitoring and evaluation visits, to disseminate the findings of the project . Key stakeholders from private industry, civil society and government were invited to attend. A survey was conducted during these workshops to determine likely characteristics of potential customers for solar agro-processing mills.

### 3.6.1 WORKSHOP AT SITE 1

The first workshop was held in Port Vila, Vanuatu during 9th August 2014. Approximately 18 people attended the workshop, many being multiple people from the same organization, and 9 complete survey forms were collected at this workshop. Technical demonstrations were made of a solar powered coconut grater, vegetable grater and flour grinder. The abilities and limitations were explained, as well as the engineering design, and attendees could then use the mills themselves. Finally, feedback was collected on the estimated price of the mills, and potential benefits for the attendees directly, or the rural population they represented.

The following results were obtained:

- 67% of attendees grew crops directly themselves, while the remainder worked with the agriculture sector but not directly engaged (Dept of Industry which oversees value-adding to crops, Dept of Energy and a coconut oil production company).
- Coconut and cassava (manioc) were the two most common crops grown by attendees. Other leading crops were taro, banana, corn and yam. Most crops were processed manually, none used electricity and one used a diesel generator.
- While decreased fuel expenditure and/or decreased costs of electricity were seen as a benefit, the strongest benefit noted in the survey was that “green” crops processed by renewable energy could add real value to the crop, allowing prices to be increased.
- The maximum payback period for survey respondents was 1 year for 40% fo respondents, but up to 4 year payback for another 40% of respondents. Payback periods longer than 4 years was not acceptable to any respondent.
- 71% of respondents would be happy to lease the equipment but would want eventual ownership. Only 11% of respondents did not find eventual ownership to be of key importance.
- Overall response was very positive, and one project was identified of 4 coconut scrapers already being used on a diesel generator that could immediately be used as a future test bed.

### 3.6.2 WORKSHOP AT SITE 2

The first workshop was held in Lae, Papua New Guinea during 25th September 2014.

Approximately 30 people attended the workshop, and 30 complete survey forms were collected at this workshop. Technical demonstrations were made of a solar powered coconut grater, vegetable chopper, flour grinder and rice mill. The abilities and limitations were explained, as well as the engineering design, and attendees could then use the mills themselves. Finally, feedback was collected on the estimated price of the mills, and potential benefits for the attendees directly, or the rural population they represented. Organizations represented included Lutheran Church Development Services, Rice Growers Associations, Appropriate Technology, Dept of Education, Digicel (a large telecommunications company), a local chain of small industrial shops, the largest rice importer, the National Agricultural Research Institute (NARI), a local newspaper, World Vision International and several local farmers. An email campaign to approximately 100 stakeholders will also allow non-attendees to receive a copy of the workshop and survey results, an important factor in a country as large and difficult to travel around as Papua New Guinea.

The following results were obtained:

- 70% of attendees were directly involved in agriculture, and 30% indirectly involved. 77% of attendees sell small retail volumes of crops while 47% are involved in wholesale. 50% grew crops directly themselves and 67% process crops themselves.
- Of 13 specific crops discussed, leading crops grown by attendees included rice (89%), coconut (50%), peanuts (44%) and coffee (39%). Cocoa, corn, cassava and millet was grown by 15-30% of attendees, while crops grown by less than 15% included taro, sweet potatoes, banana and canola. This is not reflective of national level statistics, so may represent a non-representative sample of PNG agriculture, and would be well complemented by additional survey responses from a wider audience. It is also believed that respondents only considered their involvement in commercial agriculture, and did not interpret the question to refer to staple crops. This underscores the importance of helping customers separate thoughts on staple and cash crops.
- 100% of respondents reported that they use diesel powered mills to process crops, with 75% using non-electric diesel engines and 50% using electric motors on diesel generators. Grid electricity was used by 67% of respondents and only 8% process manually (women's groups). This result is reflective of a country with low access to electricity, and frequent power cuts.
- While decreased diesel fuel expenditure was seen as the major benefit (27%), the same number noted that reduced travel time to visit distant mills would be an advantage. However, the leading benefit (33%) was the perception that there would be less breakdown and maintenance with solar powered mills, a perception yet to be proven in the field. "Green" marketing and decreased grid costs were seen as minor benefits, a contrast to Vanuatu. A key interesting comment from many participants is that women rarely use diesel equipment, but there was very strong interest from women in the "less complicated, less dirty" solar mills.

- The maximum payback period for survey respondents was as follows: 6 months (21%), 1 year (0%), 2 years (29%), 3 years (14%), 4 years (14%) and 5 years (21%). Payback periods longer than 5 years was not acceptable to any respondent.
- 83% of respondents had a preference to pay cash, while 50% were open to leasing with eventual ownership. 33% of respondents would accept leasing without eventual ownership. 50% showed interest in leasing short-term only just for special occasions. The average payback period for those preferring cash sales was 2.5 years, while those preferring to lease had an average payback period of 3.5 years.
- Overall response was very positive, and NARI, Trukai Rice and Spectra would be an almost definitely be cash customers for the first solar rice mills. Spectra would possibly prefer the 250-750W models with a lower cash cost for their retail stores, while the larger institutions may prefer larger 1-2kW units to be direct replacements for small diesel systems.

## 3.7 OTHER RESULTS

### 3.7.1 ENVIRONMENTAL ISSUES

Solar agro-processing has the potential to replace small diesel-powered mills globally, and their undesirable environmental effects and fuel insecurity.

The entire project is only 5.5 months long, and the mills have only been installed in the field for 2 months after desktop studies, investment mobilization and procurement were completed. None of the installations aimed to explicitly replace an existing diesel-powered mill, but more to show this potential was possible. Indeed, the more specific aim of the project has been the opportunity to fill the “power gap” between the maximum power a villager can sustain in manual agroprocessing (<200W) and the minimum power that the smallest diesel mill can provide (2000W).

Therefore, no savings in diesel fuel use, CO2 savings or black carbon reductions have been achieved to date. However, as the project ends but efforts to install more mills continue by VIA and others, future environmental benefits are expected to accrue.

It is not expected that CO2 savings would improve the financial viability considerably. The major financial benefit is from the saving of diesel fuel, or from earnings that can be made from the time saved thanks to reduced manual labour. Saving a litre of diesel fuel can be worth $1-2 depending on local price of fuel. A litre of diesel fuel emits approximately 3.16 kg of CO2. Based on a current price of $5/tonne and a potential price in future years of up to $50/tonne, the value of CO2 savings for one litre of diesel fuel is $0.016-0.16, currently less than 2% of the financial savings at current prices. While this may rise to 5-15% additional revenue if carbon markets recover, this is not likely in the short term.

#### 3.7.2 PROMOTIONAL VIDEO

A 9 minute promotional video has also been prepared to aid with the dissemination of the project's design and findings, and possibly may assist in raising additional investor capital over the longer term. The video can be viewed at https://www.youtube.com/watch?v=b6DxLmNM6AQ, publicly viewable for as long as the client allows.

# 4 CONCLUSIONS

The project has reached the following conclusions

- Manual and diesel powered agro-processing are the main methods staple and cash crops are processed in countries with low access to electricity, such as the focus geographies of this study, Papua New Guinea and Vanuatu in the Pacific. Manual processing is commonly undertaken by women and children, while diesel mills are generally operated by men.

- Solar agro-processing shows great potential to disrupt an estimated market in the Pacific of approximately 2000 small offgrid diesel mills worth around $4 million, with payback periods estimated at 2-5 years, which matches the expectations of surveyed customers (average expectation of 2.5 years of cash customers and 3.5 years for leasing customers)

- Solar agro-processing can fill a "power gap" - more power than manual labour can achieve (100-200W) but less than the smallest diesel mill (2000W). Small solar mills of 200-500W can process 10-50 kg/hour, serving 5-15 households, while larger solar mills can process at 50-150 kg/hr for 15-50 households. This is a better match to the median size of village in developing countries of 30-50 households per village, and given diesel mills are generally found in larger villages of 100-200 households, reduces travel costs for smaller villages who can now have their own mill.

- Solar milling benefits include saving diesel fuel expenses, but just as importantly, highly reduced maintenance, reduced transport, increased crop value for "green" marketing and a perception that solar mills are far more women-friendly and easy to operate than diesel mills.

- Investor willingness to lend for such projects has been tested and found to be supportive, with 5% p.a. 3-year $10,000 loan extended to the entrepreneurs in this project.

- Solar agro-processing offers, for most parts of the Pacific where solar insolation is strong, a very high potential to completely replace diesel agro-processing within the next 5 years. Exceptions would include high rainfall areas such as the PNG highlands where solar insolation is less dependable.

- Some larger solar mills could be designed to utilize both solar-powered DC electric motors as well as belt-driven diesel engines or AC electric motors running from diesel generators, such that if solar resource is insufficient to meet demand, the diesel backup is available.

- It is recommended to avoid AC electric solar systems that include inverters, and concentrate future work on converting agro-processing machines to run on DC motors directly from solar panels or batteries, avoiding the cost and system complexity of an inverter.

- It is not recommended that battery-free "direct-drive" systems be pursued, as small interruptions in solar resource availability such as heavy short rainbursts or cloud cover (common in the Pacific) would then cause the solar mills to stop. 30-60 minutes of battery storage is recommended as a minimum.

## APPENDIX A: SUMMARY OF TECHNICAL OPTIONS FOR SOLAR AGRO-PROCESSING

The following tables summarize the current methods used to manually process staple crops, and also diesel powered mills, where available.

| Crop(s) | Process | Manual Method | Manual Technologies | Manual Processing Rate | Diesel Mill Technologies | Diesel Mill Processing Rate | Diesel Power (kW) |
|---|---|---|---|---|---|---|---|
| Cassava, Yam | Grating |  | Local stick from bush or $3 "home made" metal grater used to grate roots finely, which are then fried as a pancake or | Cassava: 2-5 kg/hr Yams: 5-10 kg/hr | No diesel grating machines commonly used, only electric. Could combine with diesel electric generator, but uncommon. | Not common, but would be 100-500 kg/hr for 0.5-2.5kW | 2-3 kW and larger |
| Rice | Hulling |  | Mortar and pestle, usually wooden, or beating with sticks | 2-5 kg/hr |  | 100-200 kg/hr | 2-3 kW and larger |
| Rice and corn/maize/cereals | Winnowing |  | Baskets and wind | 5-10 kg/hr | Usually embedded in the hulling machine | Usually embedded in the hulling machine | Usually embedded in the hulling machine |
| Corn/maize, other grains, rice | Threshing |  | Usually none, sometimes sticks for removing rice grains from paddy | 5-10 kg/hr |  | 500-3000 kg/hr | 2-3 kW and larger |
| Corn/maize, other grains, possibly cassava | Grinding |  | Corn kernels crushed between rocks, or ground using a manual grinder (like meat grinder) | 2-5 kg/hr |  | 75-150 kg/hr | 2-3 kW and larger |
| Coconut | Scraping |  | Coconut meat can be scraped in 1-3 minutes on a sharp-toothed metal tool fixed to the end of a stool | 5-10 kg/hr | No diesel coconut scraper exists, but can be an electrical diesel generator + electric coconut scraping machines | 30 kg/hr of wet coconut meat per 200W scraper possible, 120-180 kg/hr with 4-6 scrapers on a 2kW diesel generator | 2-3 kW and larger |
| Coconut, mustard, palm, others | Oil Expelling |  | Grinding stones, or coconut meat is fermented to separate out the oil | <1 L/hr |  | 40-70 L/hr and larger | 5-8 kW and larger. Almost no options at 2-5kW size for diesel. |
| Herbs, vegetables | Chopping |  | Knife, chopping board | 5-10 kg/hr | No diesel food chopper exists, but can be an electrical diesel generator + electric food chopper machine | 300-1000 kg/hr using 1-2kW vegetable processing machine (slice/dice/shred) | 2-3 kW diesel |
| Meat, kava | Mincing |  | Manual meat grinder | 2-5 kg/hr | No diesel meat mincer exists, but can be an electrical diesel generator + electric meat mincing machine | 300-600 kg/hr using 1-2 kW meat mincer | 2-3 kW and larger |
| Fish, milk, other | Refrigeration |  | If any non-electric cooling is possible in the village, it will be putting large purchased ice blocks into an icebox or un- | 40-400 L iceboxdes and deep freezers used | No diesel refrigerator exists, but kerosene and gas refrigerators exist. Diesel and gasoline electric generators are often used to run | 50-500 L and larger mini and full size freezers and refrigerators, 300-400 L typical | 1) 1 L/day kerosene/gas refrigerators, or 2) 600-2000W gasoline generators run for 6-12 hours, or 3) 2-3 kW diesel generators run for |

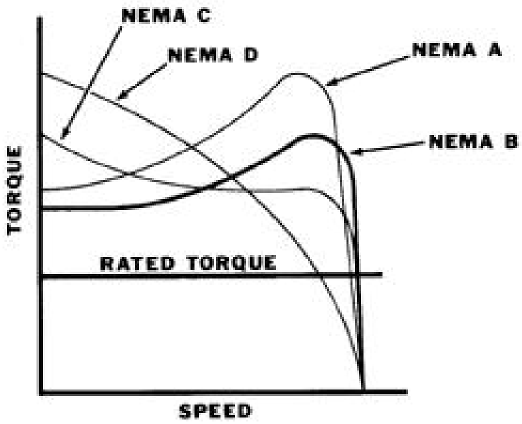
Typical processing rates are 1-10 kg/hr using manual methods, while the smallest diesel mills are 2-3 kW which process 100-500 kg/hour. Therefore, diesel powered agro-processing is typically 50-100 times faster than manual methods, and hence often serve 50-100 households per hour of use (100-200 households is normal for an average of 2 hours operation per day during the year, which can be significantly higher during harvest season).

Solar agro-processing can use existing electrical food processing equipment that uses AC power, such that an inverter is used in the solar system to provide conventional AC power. Conversions to DC power may also be possible sometimes, particularly where the motor is separate and connected to the mill externally. Both smaller and larger mills have been reviewed - the focus is not as much to offer alternatives that directly replace diesel mills, but to fill the gap between human manual power (<200W) and less than the smallest diesel powered mills (>2000W). The smaller mills typically require 150-350W and process 10-50 kg/hr, while larger mills require 1.1-2.2 kW and process 100-500 kg/hr. The solar panel power required for each hour of use for small mills is 80-200W, while for larger mills, is 500-1000W.

| Crop(s) | Process | Solar Mill Technology Options | | Solar Mill Processing Rates | | Solar Mill Power (kW) | |
|---|---|---|---|---|---|---|---|
| | | Smaller | Larger | Smaller | Larger | Smaller | Larger |
| Cassava, Yam | Grating |  |  | 50 kg/hr | 200 kg/hr | 0.18 kW for mill 80W of panel per hour of use | 1.1 kW for mill, 500W of panel per hour of use |
| Rice | Hulling |  |  | 20 kg/hr | 100 kg/hr | 0.35 kW for mill, 160W of panel per hour of use | 1.1 kW for mill, 500W of panel per hour of use |
| Rice and corn/maize/cereals | Winnowing | included in hulling machines | included in hulling machines | included in hulling machines | included in hulling machines | included in hulling machines | included in hulling machines |
| Corn/maize, other grains, rice | Threshing |  |  | 500 kg/hr | 2000 kg/hr | 0.5 kW for mill, 200W of panel per hour of use | 2.2 kW for mill, 1000W of panel per hour of use |
| Corn/maize, other grains, possibly cassava | Grinding |  |  | 30 kg/hr | 100 kg/hr | 0.25 kW for mill, 100W of panel per hour of use | 1.1 kW for mill, 500W of panel per hour of use |
| Coconut | Scraping |  |  | 10-15 kg/hr | 120 kg/hr | 0.25 kW for mill, 100W of panel per hour of use | 1.1 kW for mill, 500W of panel per hour of use |
| Coconut, mustard, palm, others | Oil Expelling |  |  | 2-3 L/hr | 15 L/hr | 0.25 kW for mill, 100W of panel per hour of use | 1.5 kW for mill, 650W of panel per hour of use |
| Herbs, vegetables | Chopping |  |  | 20 kg/hr | 500 kg/hr | 0.18 kW for mill 80W of panel per hour of use | 1.1 kW for mill, 500W of panel per hour of use |
| Meat, kava | Mincing |  |  | 70 kg/hr | 250 kg/hr | 0.25 kW for mill, 100W of panel per hour of use | 1.1 kW for mill, 500W of panel per hour of use |
| Fish, milk, other | Refrigeration |  |  | 50-225 L | 300-400 L | 40-80 kWh/year 40-80 W of panels for 24-hour use | 300-400 kWh/year 300-400 W of panels for 24-hour use |

## APPENDIX B: NAMEPLATE ESTIMATIONS OF SURGE CURRENTS

Surge currents can be estimated from the nameplate information if a NEMA class of motor is mentioned. Different motors require a different amount of surge current, as shown in the figure to the right - some instantly deliver high torque, while others ramp up over the first second or so.




The following table can be used to estimate the starting current requirements based on the NEMA class of motor on the nameplate. As an example, a E class motor would require about 4.75 kVA per horsepower of the motor, so a 1/2 hp (375 W) motor would require 2.4 kVA during startup. At 220V (and single phase), this would be 11 Amps, but from a 12V battery, 198 Amps would be required.

| Code Letter | Kilovolt-Amperes per Horsepower with Locked Rotor |
|---|---|
| A | 0-3.14 |
| B | 3.15-3.55 |
| C | 3.55-3.99 |
| D | 4.0-4.49 |
| E | 4.5-4.99 |
| F | 5.0-5.59 |
| G | 5.6-6.29 |
| H | 6.3-7.09 |
| J | 7.1-7.99 |
| K | 8.0-8.99 |
| L | 9.0-9.99 |
| M | 10.0-11.19 |
| N | 11.2-12.49 |
| P | 12.5-13.99 |
| R | 14.0-15.99 |
| S | 16.0-17.99 |
| T | 18.0-19.99 |
| U | 20.0-22.39 |
| V | 22.4-and up |

Ref: http://www.mastercontrols.com/Articles/Barr/TA_RBarr.htm