# FOOD ISSUES

## Renewable energy for food preparation and processing

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## WISIONS INITIATIVE

WISIONS of sustainability is a Wuppertal Institute initiative that is supported by the Swiss-based foundation ProEvolution. The initiative was launched in 2004 to promote practical and sustainable energy projects – particularly those in developing countries.

As well as the Technology Radar, which serves as an information tool, practical financial support for the implementation of innovative and feasible energy projects is provided via SEPS – Sustainable Energy Project Support. To date more than 50 projects around the world have been selected for SEPS support.

## WISIONS TECHNOLOGY RADAR

The aim of the WISIONS Technology Radar is to give a comprehensive and transparent overview of the existing renewable energy technologies and their possible contribution to meeting basic energy needs. It serves as a scientifically based source of information on solutions for addressing the global challenges related to the need for energy.

Key questions addressed for each technology refer to the technology's potential contribution to global sustainable development and its potential to achieve the Millennium Development Goals. In addition, the environmental, social and regional impacts that are linked to the implementation of the technology are examined. Where possible, development options for the future are also analysed, as well an appraisal of the set up necessary to ensure the technology is economically viable.

This, the second brochure, summarises key findings on energy solutions for the preparation and processing of food using local and renewable energy resources. More data, examples and information are available on our internet platform, www.wisions.net, under the heading "Food Issues".

## SEPS CASE STUDIES

Case studies, supported under SEPS – Sustainable Energy Project Support – illustrate the practical implementation and lessons learned in the field. In addition to examining the technical and economic viability of the projects, environmental and social aspects are highlighted. Some successful examples of these projects are described in this publication and also feature on our website, www.wisions.net.

# FOOD ISSUES

## RENEWABLE ENERGY FOR FOOD PREPARATION AND PROCESSING

Food is a basic human requirement, as is its production and preparation. We need food to live. Food preparation methods, such as frying, boiling and baking – as well as other food processes, like drying, refrigeration or milling – are all linked to the provision of energy.

- Energy and food preparation

One of the main uses of energy in households in developing countries is for cooking (i.e. the preparation of daily meals). Around one third of the world's population relies on biomass as a principal source of energy for domestic needs, i.e. mainly cooking and heating [1].

Biomass is, in principle, a renewable resource; however very low quality combustion is an almost universal characteristic of the most widespread biomass energy technologies (e.g. traditional cooking stoves or ovens). The incorrect combustion of biomass releases high levels of unhealthy pollutants, which are associated with diverse respiratory diseases. The World Health Organization estimates that indoor air pollution is responsible for 3.7% of all the diseases in developing countries and up to 1.5 million people die each year as a consequence of this pollution [2].

Poor quality biomass combustion also means that only a small fraction of the biomass energy content is effectively transformed into useful heat. As a consequence, the demand for biomass to meet basic household needs is greater than it would be if more efficient techniques were widely applied. In many regions biomass resources are becoming increasingly scarce and the rising demand for biomass is leading to deforestation, desertification, higher costs or longer collection times.

Women and children in particular are the ones who suffer most from indoor air pollution and they also spend a significant amount of their time collecting firewood or dung to use as cooking fuel.

- Energy and food processing

The adequate postharvest handling of agricultural produce can play a key role in providing food security and in supporting the development options for farmers in developing countries.

Postharvest losses of fruit and vegetables of up to 50% or even higher have been reported in tropical and sub-tropical regions [3]. These losses are due to the perishable nature of the produce, poor harvest handling, poor marketing and a lack of affordable and appropriate postharvest technology.

As well as improving preservation, adequate food processing may also improve the economic value of crops, for example by making food more palatable, developing flavours, facilitating packaging and transport or producing products of higher nutritional value.

Many food-processing methods require thermal or mechanical energy. Energy supply infrastructures in many regions in developing countries are often either unreliable or even nonexistent. Additionally, commercial food-processing devices are often unsuitable for the specific technical and economic conditions of farmers in developing countries.

- Food Issues in the Technology Radar

The use of renewable energy sources for food preparation and processing is not new. Many traditional (ancient) practices use

renewable resources, such as cooking with firewood, drying in the sun or using watermills. However, many technical advances can improve the performance of familiar techniques and new concepts can lead to alternative processing options that use renewable energy.

The Technology Radar examines options that can make a significant contribution to meeting the energy need for food preparation and processing for populations that lack access to a reliable and affordable modern energy supply. Only technologies based on the use of renewable energy sources are considered. Comprehensive and transparent information on promising technologies is available online under the heading "Food Issues". This brochure examines some of those technologies that have been emerging as key options in the global context.

## ENERGY FOR COOKING – IMPROVING THE WELLBEING OF THE HOUSEHOLD

Attempting to improve cooking technology is not a new phenomenon. A multitude of initiatives (from large national or regional programmes to local projects focused on very specific communities) have addressed the challenge of developing and promoting more sustainable energy technologies to meet cooking needs.

Today a huge amount of valuable knowledge is available. Many technological options have evolved that respond to the specific characteristics and requirements of the user:

- Solid biomass stove

Improved designs of biomass stoves are among the most promising options. The most advanced concepts guarantee optimal combustion, high levels of energy efficiency and a significant reduction (or avoidance) of unhealthy pollutants.

This new generation of stoves represents the most accessible option for millions of households to improve some aspects of their wellbeing while retaining the use of solid biomass as their main energy source.

- Biogas stove

Cooking with biogas is particularly appropriate for households and communities where fenced animal husbandry is already a traditional practice. Biogas solutions are, however, also finding applications in many other cases.

Using anaerobic digestion for the treatment of organic waste has been emerging as an appropriate technology for a wide range of households. As well as producing biogas, the technology provides a solution to other critical issues, such as reducing pollution from organic waste and recuperating nutrients for the soil.

- Solar cooker and oven

Although the use of solar radiation is probably the cleanest option for cooking (and the 'fuel' is 'free'), solar technology cannot, generally, be used as a stand-alone solution.

When the climatic conditions are suitable, solar cooking and baking solutions can be excellent complementary technologies that can significantly reduce the demand for other energy sources.

- Other cooking options

The use of liquid biofuel, such as plant oil or bio-ethanol, is emerging as an option for meeting the energy needs for cooking in households in developing countries.

These technologies can currently only be applied in regions where a market for the corresponding biofuel already exists, or is likely to emerge. The potential effects of widespread use of liquid biofuel would need to be critically analysed in terms of its environmental, social and economic impacts.

## ENERGY FOR FOOD PROCESSING – IMPROVING THE VALUE OF AGRICULTURAL PRODUCE

The development of food processing technologies adapted to the conditions and demands of farmers in developing countries has received less attention than the area of household cooking.

However, diverse concepts have been developed and tested, which indicate that huge potential exists to improve the post-harvest treatment of produce by using renewable energies. Most of these concepts are still niche specific and, generally speaking, innovative efforts are needed in order to develop more robust and better-adapted solutions that can be widely disseminated.

- Drying

Different designs of solar dryers have been emerging. Models have been adapted to suit specific climatic conditions, the type of product and expected quality. However, poor quality manufacturing and performance is still common. Generally every dryer is unique, and maintenance and repair require greater than ordinary technical skills.

The benefits of drying agricultural produce are directly related to the availability (or likelihood) of a market for dried products. Consequently, as well as making developments in terms of better quality and standardisation, efforts are also needed to better understand the market options for dried products.

Another interesting field of innovation is the application of hybrid systems that use a secondary energy source, such as biomass and biogas, as backup for gloomy days and at night.

- Refrigeration

Reducing the temperature of produce is one of the most effective ways of preserving food. There are many technical solutions that use renewable energy to power refrigeration. However, mature designs that appropriately respond to the cooling needs of agricultural produce are still rare.

Some designs of solar PV refrigerators are commercially available. This is still a very expensive technology and is mostly used for medical refrigeration.

Solar thermal collectors and biogas combustion are potentially interesting in terms of driving refrigeration cycles. Different concepts have been developed and tested; however, hardly any designs have become commercially viable.

The cooling effect of evaporation is a simple method that has been successfully applied for reducing crop losses in some regions. However, it is only possible to use evaporative cooling in areas with dry and hot climates.

- Milling and pressing

Milling grains and pressing oils are some of the most common postharvest activities in developing countries. Using water or wind power to drive mills and presses is an option that has been recognised and used since ancient times.

In modern times, diesel engines and electric power have generally replaced the use of water and wind energy. However, improving ancient concepts by applying advanced techniques can give these traditional technologies a new lease of life, particularly by enhancing energy conversion efficiency and productivity.

Combining renewable power generation technologies with modern conventional milling and pressing devices can also open up new innovation opportunities to develop stand-alone solutions for population/regions lacking access to energy infrastructures.

However, activities aimed at developing these potentials are still few and far between. Greater efforts in terms of research, demonstration and deployment are needed before mature designs of modern renewable mills and presses can become a reality.

Applied examples/projects and details on the characteristics of the single technologies, as well as the criteria for their implementation, are outlined in this brochure.

# SOLID BIOMASS STOVE

The direct combustion of solid biomass is probably the oldest household technology and will continue to be the main energy source for cooking, water heating and domestic heating in many developing countries for years to come. A wide range of stove types that use solid biomass as fuel can be found around the world. However, very low quality combustion is an almost universal characteristic of the most traditional and widespread stoves. Two prominent disadvantages derive from the use of these inefficient stoves:

- Low efficiency: only a small fraction of the biomass energy content is effectively transformed into cooking heat
- Unhealthy emissions: a wide range of health-damaging pollutants are released in the flue gases

Several models of alternative (improved) stoves already exist, offering the option of using solid biomass energy sources for cooking, but in a more efficient and cleaner way. However, the large-scale global diffusion of improved stoves is still a goal that should be pursued.

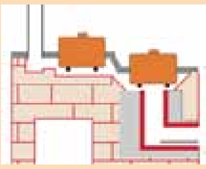
Almost any kind of dried organic matter can be used as fuel for cooking e.g. agricultural residues (such as stalks, husks, shells, etc.), manure or wood in either its 'green' or charred form. However, the performance of any stove greatly depends on the properties of the biomass used: the physical characteristics (e.g. size, moisture content, density) of the fuel, the biochemical composition and the energetic value.

Biomass resources can also be processed in order to improve their properties of transportability, combustion etc. Some notable examples are:

- drying to reduce moisture;
- cutting, chipping or briquetting to facilitate transportation and/or improve combustion;
- producing charcoal (by pyrolysis) to improve energy density and burning characteristics.

The type and size of the fuel determine the design of the combustion chamber of the cookstove and air supply required. Almost no single stove design is suitable for burning all types of solid biomass. This means that the kind of cooking fuel available in a region is a crucial parameter when it comes to designing and selecting appropriate solid biomass stoves for a target population. Table 1 illustrates a small selection of stove designs. The selected examples were classified into portable models and fixed stoves, i.e. those for integration into the kitchen space.

Table 1. Some (a few) examples of improved biomass stoves
Sources: WISIONS own documentation; Hedon Stove Database (www.hedon.info); [26]; [27]

| Fixed | | Portable | |
|---|---|---|---|
| **Improved "Chulah"**<br>• Many variations; possibly with chimney<br>• Fuel: 'green' biomass<br>• Region: mainly in Asia |  | **Thai Bucket**<br>• Many variations; inner core ceramic; metal mantel<br>• Fuel: mainly charcoal<br>• Region: Asia |  |
| **"Inkawasi"**<br>• Two pots; chimney<br>• Fuel: 'green' biomass<br>• Region: Peru |  | **Ceramic "Jiko"**<br>• Many variations; inner core ceramic; metal mantel<br>• Fuel: mainly charcoal<br>• Region: East Africa |  |
| **Rocket Lorena**<br>• Two pots; chimney<br>• Fuel: 'green' biomass<br>• Uganda, Kenya |  | **"Sampada"**<br>• Gasification; low power; charcoal production<br>• Fuel: 'green' biomass<br>• Region: India |  |
| **"Jinqilin"**<br>• Industrial production; semi-gasifier; chimney<br>• Fuel: 'green' biomass<br>• Region: China |  | **"Envirofit"**<br>• Industrial production<br>• Fuel: 'green' biomass<br>• Region: India |  |

## GLOBAL SUSTAINABLE ENERGY SUPPLY

Accelerating the dissemination of improved solid biomass stoves is one of the main means of achieving universal access to clean cooking facilities [1]. Improvements in energy efficiency through the introduction of improved stoves can significantly reduce the pressure on valuable biomass resources that currently provide energy for cooking. The global alliance for clean cookstoves aims to promote the diffusion of improved biomass stoves, with a target of 100 million such stoves to be in use by 2020 [4].

## MILLENNIUM DEVELOPMENT GOALS

Up-scaling the adoption of improved biomass stoves is a crucial factor in achieving the MDGs. The use of energy efficient and cleaner solid biomass stoves impacts positively on factors driving the vicious cycles of poverty, such as improving health conditions at home and freeing up time and/or reducing the cost associated with the provision of energy for cooking.

## DEVELOPMENT STATUS AND PROSPECTS

Some issues that may contribute to the further development and dissemination of the technologies are:

- Solid data on performance and impacts

The performance of any stove depends not only on its technical design, but also on other factors such as the characteristics of the available fuel and, in particular, the traditional cooking habits of the user (as this impacts on how they will use the stove). Assessing the actual benefits to the user requires testing the stoves under real conditions. Greater effort is still needed to compile a solid base of data comprising a broad range of regions and technologies. This information source is a crucial factor in shaping the plans for up-scaling the adoption of improved biomass stoves.

- Standardising test methods

Comparing the widely diverse stove designs is almost impossible. Evaluating and comparing technical options is crucial when making decisions at different levels (e.g. for the design of government programmes, for industry strategies, marketing, or even for individuals). Some methods have commonly been used for testing biomass stoves, such as "water boiling tests", "controlled cooking tests" and "kitchen performance tests" [5]. However, efforts to further develop appropriate methods and to gain broader acceptance and application of the standards are still required.

- Development of regional/national standards

The suitability of a stove design varies from region to region. It depends on several cultural, economic, social and technical factors. It is very unlikely that only one concept could respond appropriately to the needs of all users even within one country or region. Consequently, the future scenario may involve the emergence of national and/or regional markets where a set of stove designs are commercialised. The designs should not only be price-competitive but also fulfil specific technical standards of efficiency and emissions. Establishing regional or national systems to formulate and ensure quality standards will be a crucial step towards the mass diffusion of improved stoves.

- Up-scaling commercialisation

There are prospects for the dissemination of improved solid biomass cookstoves on a wide scale, especially in rural areas. To support this development a programme called the UN Global Alliance for Clean Cookstoves has been initiated. The aim is to help to overcome existing market barriers that currently impede the production, deployment and use of clean cookstoves in the developing world. The target is to increase the number of improved cooking stoves to around 100 million by 2020.

An interesting field of innovation is the development of so called "micro-gasification". The basic idea consists of applying the principle of gasification for cooking. This is a relatively recent development. Several concepts have been already tested and further development of the technology promises to respond to some important issues related to cooking with biomass [6]. The technology offers three notable advantages:

- The option of using different kinds of biomass residues (e.g. rise husk, nut shells, straw, wood chips), which are not traditionally used as fuel for cooking.
- The whole thermal process can be more efficient and cleaner than the direct combustion of biomass.
- Some concepts offer the possibility of generating (bio) charcoal as a by-product of partial gasification. This kind of charcoal seems to be an excellent substrate for soil recovery or enhancement.

# SOLID BIOMASS STOVE CASE STUDY 1

## PROMOTING IMPROVED STOVES IN XIENGKHUANG PROVINCE, LAOS

### PROJECT'S AIM

To introduce improved stove technology and know-how to areas with wood fuel scarcity, resulting in better living conditions for the local population.

### PROJECT DESCRIPTION

Most people in Laos rely on wood fuel as their main energy source for cooking and heating. In some areas wood fuel is scarce and people spend a lot of their time and money to meet their daily cooking and heating energy needs. One of the regions with an acute wood fuel shortage is the Xiengkhuang province and, in particular, the Paek District. The reasons for the wood fuel shortage and the resultant high prices for firewood are twofold. On the one hand, the shortage is due to natural circumstances such as low soil quality and water shortages during the dry season. This is compounded by external causes, such as the heavy bombing of the region during the liberation war in the sixties and seventies, which resulted in a lack of available forest resources.

In order to improve the energy situation and protect the environment in this region, the Technology Research Institute (TRI), in close cooperation with the Provincial Science, Technology and Environment Office (STEO), initiated this project. The aim was to introduce more efficient wood stoves to the local communities. The stoves that were traditionally used were very inefficient, ranging from traditional three stone stoves, over iron tripods, to stoves that could burn wood fuel as well as charcoal.

The project consisted of three phases. The objective of the first phase was to gain acceptance of the improved stoves and to establish a baseline to measure the performance of the new stoves. 60 stoves were purchased from a manufacturer in Ventiane, the capital of Laos, and distributed to local women's unions in three target villages. The intention was to collect information about how appropriate the stoves were for the local conditions and to measure the fuel consumption of the improved stoves compared to the other stoves in use in local households. The second phase saw the introduction of local production of the improved stoves. During the course of two workshops, nine artisans, most of whom were traditional stove producers, were trained in all the processes of improved stove production. The participants were equipped with standardised tools to produce the improved stoves. At the same time, a promotion campaign was initiated to target potential users. In the final stage of the project the results of the improved cooking and heating stove project were published to make provincial and national authorities aware of the benefits of improved stove use. Training and information material was also produced in order to promote the introduction of improved stoves.

**Location:**
Xiengkhuang Province, Laos

**Costs:**
Total: ca. € 18,000
WISIONS financial support: € 17,900

**$CO_2$ Reduction:**
4,500 t $CO_2$/year*
(*estimate of non fossil fuel $CO_2$ emission reduction from biomass burning)

**Partners Involved:**
Technology Research Institute (TRI)

**Duration:**
01/2007 - 11/2008

### TECHNOLOGY, OPERATIONS AND MAINTENANCE

The improved cooking stove design chosen for the project was not the most efficient stove design, but was the most suitable for the local conditions. It has a wide opening so that it is possible to use large pieces of wood. The users of the imported stoves during the test phase were satisfied with the stove performance in terms of smoke reduction, shorter cooking times and, in particular, lower firewood consumption.

After the successful introduction phase, stove producers were trained to manufacture improved wood stoves locally. By the end of the project, two of these producers had already started manufacturing the improved stoves alongside the traditional stoves. To ensure a future market and the long-term success of the technology, quality control in form of user feedback was an integral part of the project. The users of the first locally produced stoves criticised the fact that the stoves cracked after a few weeks of use. To overcome this problem the ratio of clay to black ash was changed from 1:2 to 1:2.5.

### FINANCIAL ISSUES AND MANAGEMENT

The firewood consumption of an average family in the project area was 6-18m3 per year depending on the family size. The villagers were either buying firewood or collecting firewood themselves. For the families who had to purchase firewood, the cost amounted to between €19 and €115 per year. By switching to the improved stoves the firewood consumption, with its related cost in terms of both money and time, could be reduced by about 20% to 50%.

The improved stoves cost around €2.50 (28,000 kip/stove) to buy, which is 1.5 to 2 times higher than a traditional stove. This price includes delivery costs and profit for the retailer. In order to convince the retailers of the viability of selling the new stoves, the initial order of 220 stoves was paid for by the project fund. These stoves were placed in local shops and the retailers only had to pay for them once they had been sold. After this first order had been successfully sold, nine retailers recognised the market potential for the improved stoves and were then willing to purchase stock upfront.

ENVIRONMENTAL ISSUES

The reduction of firewood consumption has two positive impacts on the environment. There is less demand on existing wood resources and, also, a reduction in the harmful $CO_2$ emissions that occur during the burning of firewood. As almost 3,000 improved stoves were in use by the end of the project period, this equates to annual $CO_2$ emissions savings of around 4,500 t. These are not reductions of fossil fuel based $CO_2$ emissions, but of inefficient biomass burning emissions.

SOCIAL ISSUES

The local population benefits from the use of improved cooking and heating stoves in the form of reduced time and work spent on firewood collection. Families who currently purchase firewood also reduce their costs and can save the money for other needs. In addition, less firewood used also means less indoor air pollution, which benefits the health of the stove users.

The project also provided technical training for local stakeholders, so that the improved stove technology can be manufactured locally. The knowledge, skills and value created through the project can provide benefits and offer income opportunities for manufacturers and retailers within the project region.

RESULTS & IMPACT

At the official end of the project in 2008, more than 2,850 improved wood stoves were in use within the project area. Two of the nine trained local artisans were already commercially producing improved stoves. In this way the project created employment and income opportunities in the region and, at the same time, users of the improved stoves save money and time because of their need for less firewood.

REPLICABILITY

Following the successful introduction of improved wood stoves in the project region, the market is expected to grow. This offers the opportunity to replicate the skill building activities throughout the region and beyond. In order to help develop the adoption of the improved stoves, promotional material in the form of two films and a training manual describing the improved stove production process was created in cooperation with the local partners. This promotional material could also be used in other rural regions of Laos to inform the population about the technology and to commercialise the improved wood stove technology. The project could also be replicated in other regions around the world that face wood fuel scarcity and similar social conditions, although the specific design of the stove would always have to be adapted to suit local conditions.

LESSONS LEARNED

The key to the success of this project was the strong support from the local authorities and the village committees.  They are familiar with the local conditions and understand the needs of the population. After these people were trained in the technology and its operation, benefits and advantages, they were able to disseminate the information to the local population in an appropriate manner.

Source: Final Report submitted to WISIONS
by Technology Research Institute

# SOLID BIOMASS STOVE CASE STUDY 2

## BUILDING PRIVATE/PUBLIC PARTNERSHIPS TO EXPAND MARKETS FOR IMPROVED HOUSEHOLD STOVES IN CHINA

### PROJECT'S AIM

To help rural households in western China to access efficient, cleaner cooking and heating stoves.

### PROJECT DESCRIPTION

The average Chinese rural family uses biomass as their main energy source for cooking and heating. Especially in the high regions of western China, with its cold and long winters, the firewood consumption is very high - amounting to as much as 18-20 tonnes of firewood per household per year (for cooking and heating). Because of the high altitude of the regions the climate is severe and soil conditions are poor, resulting in very low vegetation growth rates. These circumstances and the current firewood consumption patterns lead to fuelwood scarcity, deforestation and land degradation in the region.

One way of improving the situation would be to introduce more efficient cooking and heating stoves, which could significantly help to reduce firewood consumption and indoor air pollution, and could also help to avoid further deforestation. However, in this part of China the market for improved metal biomass stoves is underdeveloped. Due to a lack of awareness and poor infrastructure, as well as consumer price barriers, this makes the rural western region quite different from other areas in China where improved stoves have already been successfully commercialised.

In the first phase of the project, the Centre for Entrepreneurship in International Health and Development (CAREI) - together with its partners - conducted a comparative study to identify the best high-efficiency, low-emissions biomass household stove in China. The second phase of the project, which is described here, aimed to disseminate that technology to the agricultural and herding communities in the western regions of China.

The tangible goal was to increase sales of improved stoves by 20,000 in two years, which would lead to social and health benefits. Therefore, the project was designed as a combined market and subsidy approach to achieve more efficient operations, lower prices and greater market coverage. Furthermore, efforts were made to subsidise stoves through carbon finance mechanisms. Consequently, a combination of household surveys and in-home fuel use studies were conducted to establish a baseline study of the carbon savings made through the project activity.

**Location:**
Shanxi, Western China

**Costs:**
Total: € 133, 500
WISIONS financial support: € 36, 000

**$CO_2$ Reduction:**
Up to 300 kt $CO_2$/year

**Partners Involved:**
Chinese Association of Rural Energy Industries (CAREI)
www.carei.org.cn

Impact Carbon (formerly CEIHD)
www.impactcarbon.org
Berkeley Air Monitoring Group

**Duration:**
09/2007 – 07/2009

### TECHNOLOGY, OPERATIONS AND MAINTENANCE

The promoted stove model is the Jinqilin semi-gasifier biomass stove, which can use both unprocessed crop residues and briquetted crop residues. The fuel is manually loaded into the stove and the fire is lit at the top so that the burning process proceeds downwards, opposite to the airflow direction. In addition, holes were added on the upper part of the stove to further increase the combustion efficiency of the stove. The stove also uses a small electric fan that forces ventilation and air turbulence in order to facilitate the combustion process. Overall, the thermal efficiency of the low-emissions biomass household stove is 35-41%, which is much higher than the 10-12% efficiency of the traditional stoves.

### FINANCIAL ISSUES AND MANAGEMENT

The project was a multi-sector collaboration between government entities, private stove companies and NGOs. Federal and provincial funds were made available to help the poorest farmers to afford new stoves. Activities such as market development, design, project documentation, monitoring and evaluation were financed through the project.

The average per capita income in the project area was about € 290 - 540 per year, while the retail price of the improved stove was about € 40. Approximately 15,000 of the distributed stoves were fully subsidised, while most of the others were sold at full price. The Rural Energy Offices of the Chinese government determined which households should benefit from a subsidy. They conducted an economic survey of households in the project area to identify the poorer households who would be unable to afford an improved stove without financial help.

### ENVIRONMENTAL ISSUES

The high-efficiency low-emissions biomass stoves that were introduced emit 50-70% less greenhouse gases, with the result that each rural household can save about 4,000 kg $CO_2$ per year. As 74,510 stoves were distributed, 300 million kg $CO_2$ per year could potentially be avoided.

In order to profit from this reduction in emissions, the project applied for Gold Standard certification. It is planned to use the money generated from carbon credits to subsidise further improved stoves in the region.

## SOCIAL ISSUES

By improving access to clean energy for cooking and heating, the project significantly reduced indoor air pollution, which is responsible for respiratory and other illnesses, especially in women and young children. Likewise, the project created employment and helped households to reduce the time and money that they spent on fuel, which had positive effects on the household incomes.

## RESULTS & IMPACT

At the end of the project the original pilot goals were all exceeded. About 74,000 households were using improved cooking and/or heating stoves. This means that, as a result of the project activities, about 220,000 people are now exposed to lower levels of indoor air pollution. In terms of employment, about 679 manufacturers (e.g., metal workers, potters, etc.) and 85 distributors were employed, and 4 new small businesses producing and marketing the improved cooking and/or heating technology were established.

The project also had an impact on the fuel source used in the region, as previously many people used coal as a cooking fuel during the warm season when no heating was required, but now they mainly use corncobs as cooking fuel. With the introduction of the Jinqilin stove, it is estimated that coal use was reduced by about 1.79 tonnes and that corncob use was increased by about 1.37 tonnes per household per year.

## REPLICABILITY

The project was very successful in disseminating the improved biomass stove technology in western China and there is expected to be good potential for expansion to other parts of rural China. With China's total rural population being about 140 million, and the current stoves sales being around 60,000 annually, there is still a huge market for stoves that reduce indoor air pollution, carbon emissions, and unsustainable fuel use. Further support from central government, under its mandate to improve the quality of life in rural areas, will help promote future replication of the project. Demonstration sites have already attracted the attention of municipal and provincial authorities looking for ways to fulfil the government mandate.

In addition, 16,000 educational posters and 20,000 end-user brochures on optimal stove usage were produced and distributed to the rural population at events, through schools and at points of sale.

## LESSONS LEARNED

The outcome of the project exceeded all expectations. One critical success factor was the co-operation of the different stakeholders and the involvement and support of the regional and national government bodies. However, although the project was very successful some problems were discovered during the implementation process.

Due to the large number of stoves that were sold it became necessary for the manufacturers to increase their factory size and capacity, but they did not have the capital or means to obtain finance for these activities. To solve this problem, factories will need to make efforts to obtain loans and strengthen their carbon credit development. Furthermore, the quality management and after-sales service needs to be improved to ensure the long term success of the improved stove technology.

It was also discovered that the stove does not meet the heating needs of Tibetan farmers. Adjustments to the thermal performance are necessary to make the stove suitable for use at very high altitude.

Source: Final Report of Impact Carbon/CAREI

# BIOGAS STOVE

Biogas is the gaseous product of breaking down organic matter in the absence of oxygen. It can be used to meet the energy need for cooking in individual households as well as in small businesses (e.g. restaurants and bakeries) or in communal facilities. Stoves for biogas application are similar to conventional appliances that run on commercial fuels such as butane and propane. However, special modifications (particularly in the design of the burners) are required in order to ensure proper combustion and the efficient use of energy.

The biogas stove is the final component in a relatively complex system, where biomass is converted into biofuel (biogas) in order to meet the energy need of people for cooking or baking, as Figure 1 schematic illustrates. The production of biogas is a laborious activity; it requires daily input from the user (e.g. collecting substrates, mixing with water, charging the biodigester, treating or disposal of digestates, etc.). Therefore, it is essential that the biogas stove (or oven) will burn the biogas in the most efficient and effective way.

Cooking or baking with biogas is relatively easy. However, anaerobic digestion is rather a complex process. Several variables can affect the anaerobic process and considerably reduce the production of methane (which is the main energy carrier in the biogas). Particularly important is the feeding of the biodigester with appropriate organic material.

## GLOBAL SUSTAINABLE ENERGY SUPPLY

The use of biogas for cooking is a promising option for improving the energy supply of the poor, i.e. over 2.7 billion people who rely on the inefficient and unhealthy burning of biomass as their main energy source. Accelerating the dissemination of biogas-based solutions in rural areas is one of the essential measures for establishing universal access to clean cooking facilities by the year 2030 [1].

## MILLENNIUM DEVELOPMENT GOALS

Stoves using biogas have the potential to improve the wellbeing of marginalised people. They offer an excellent opportunity to put an end to the indoor pollution generated in the kitchens of many poor families around the world. Biogas solutions for cooking generally depend on the user producing the fuel (biogas) by using available organic waste. This can have a positive impact on the vicious cycle of poverty by freeing up time, reducing energy costs for cooking and avoiding pollution from organic wastes.

However, biogas solutions for cooking depend (in the first instance) on the technical feasibility of users producing their own fuel (biogas). This means that the broad diffusion of the technology requires a thorough assessment of the potential and requirements of the target population.

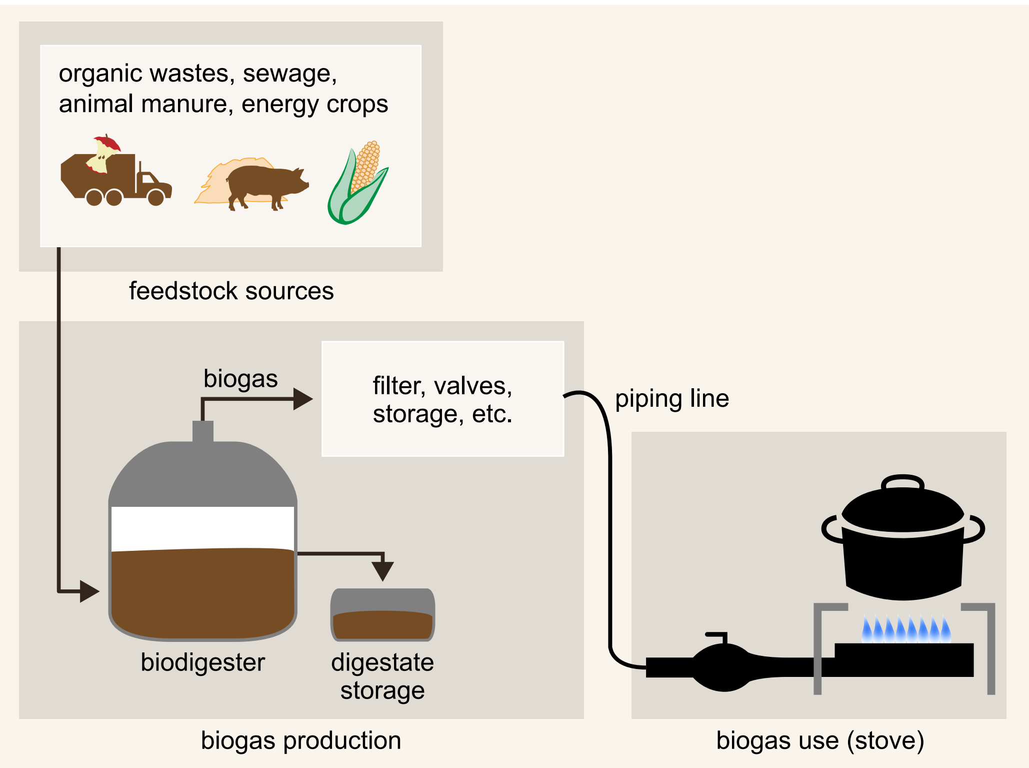



Figure 1. Schematic view of a biogas system where biogas is used for cooking

## SOCIAL ISSUES

Assuring the long-term adoption of the technology has proved difficult in many cases. Some key issues affecting the adoption of biogas technologies are:

- Awareness of user input and limitations to the technology

The operation of a biogas system necessitates regular user input. These tasks generally mean that users have to change their traditional practices. How difficult it is to make these changes may depend on the usual activities of the user, as well as on cultural factors and religious beliefs; e.g. it may be easier for milk producers (whose animals are commonly confined in a stable, at least during milking) than for breeders whose cattle graze freely.

The availability of water and technically appropriate and cultural accepted substrates may also limit the application of the technology, e.g. human excreta is an outstanding substrate for biogas production, but its productive use may face strong cultural barriers.

- Supervising the start and training the users

Starting the anaerobic digestion process can take from two weeks up to two (or more) months. Providing appropriate assistance to the users during this phase is crucial in order to build up their confidence in the technology.

Anaerobic digestion is a complex biochemical process and its stability depends on many parameters. Therefore, building and transferring knowledge to users about appropriate monitoring and operation strategies is crucial for the sustainable use of the technology.

## ECONOMIC ISSUES

New users do not only have to invest in a biogas stove but also in other components such as the biodigester, distribution pipes and (eventually) storage.

The major cost is the biodigester. Total investment depends mainly on the kind of biodigester and its size. There are many types of biodigesters used for household systems. Another important cost factor is the distance between the biodigester

and the kitchen. The cost of a small biogas system (biodigester capacity from 4 to 6 cubic meters) ranges from US$ 200 to US$ 1000 [7], [8].

These figures generally only include the cost of materials for the biogas system. Labour and other materials required for site preparation and installation are expected to be covered by the user's own resources. Additionally, programmes supporting biogas solutions commonly absorb the more "intangible" costs such as technical advice, monitoring services, operational training and the cost of marketing, awareness campaigns and research and development of the technology.

# BIOGAS STOVE CASE STUDY 3

## REPLACING FIREWOOD WITH BIOGAS IN NAKURU HIGH SCHOOLS, KENYA

### PROJECT'S AIM

To substitute firewood with biogas technology for providing clean and sustainable energy at Kenyan boarding schools.

### PROJECT DESCRIPTION

In Kenya, nearly all educational institutions rely on firewood as an energy source for cooking, making the educational sector a major firewood consumer. Such heavy dependence causes environmental problems in the form of deforestation as well as placing a financial burden on the institution itself due to rising firewood prices. To improve the current situation "IT Power Eastern Africa" initiated a project in which biogas technology was introduced as an alternative energy source.

Although biogas technology is not new in Kenya, many of the installed biogas plants are not operational - due mainly to their incorrect management. This has had negative effects on the acceptance and dissemination of the technology. As a result, a major part of the project has since concentrated on local capacity building and the development and distribution of technical manuals for installers and end users. These efforts should ensure the quality and standardisation of biogas technology.

In the pilot phase, the project targeted two selected boarding schools in the Nakuru area. The chosen substrate for the biogas generation was cow dung. As the schools operate small farms, including farmed livestock, dung is readily available. To ensure the sustainability of the project, a revolving fund for participating institutions and micro-credit institutions was established. In addition, a National Biogas Workshop was held to promote the use of institutional biogas plants to facilitate widespread dissemination of the biogas technology in Kenya.

**Location:**
Nakuru, Kenya

**Costs:**
Total: € 52,000
WISIONS financial support: € 39,000

**$CO_2$ Reduction:**
Up to 74.5 t $CO_2$/year

**Partners Involved:**
IT Power Eastern Africa
(www.itpower.co.uk)

**Duration:**
2007 – 2010
(with interruptions)

### TECHNOLOGY, OPERATIONS AND MAINTENANCE

The installed biogas plants have a capacity of $50m^3$ and can produce around $10m^3$ of biogas per day. Two of the three installed plants were constructed below ground, out of locally available materials. The third plant, at Nakuru Girls High School, was built above ground. The reason for the different construction method was that the ground at the girls' school proved to be extremely rocky. After various attempts to excavate the ground, the project management decided to build the plant on the surface. This caused a delay, so by the end of the project only the two biogas plants at the Nakuru Boys School were running.

The biogas is transported through a pipeline to the school's kitchen where two biogas stoves were built with cement and are used for boiling water and preparing vegetables. However, the construction of the biogas cookers had to be improved, as they did not initially work properly. The reason for this was that the oxygen supply was insufficient and the flame was inconsistent.

The residues from the biogas generation are used as fertiliser in the school's vegetable garden. During a visit to the project site it was discovered that there were no distribution pipes or storage trenches for the liquid manure, but ways to improve the storage and means of spreading the fertiliser were sought.

### FINANCIAL ISSUES AND MANAGEMENT

In contrast to ten years ago, when firewood was collected from the school's forests, schools now purchase almost all their firewood. Prices have doubled within the last five years, due to the scarcity of firewood in the region. Nakuru Boys High School used about 300 tonnes per year, costing 1 Mio. KSH (around 100,000). The reduction in firewood consumption, due to the use of the biogas plant, means that schools can reduce their expenses significantly. As a result, the cost of the biogas plants can be recouped within 2-3 years and the annual energy costs - paid for by the pupils - are also reduced.

To ensure the long-term sustainability of the project, it was very important that the schools financed the installation of the plants themselves. At the beginning, 50% of the total cost was met by the schools while the remaining 50% was provided as a 'soft loan' through financial assistance from WISIONS. Once this loan is repaid, the money can be lent again to other educational institutions to install biogas technology.

### ENVIRONMENTAL ISSUES

Reducing firewood use in Kenyan schools can benefit the environment in multiple ways. On the one hand, exertion on the local forest resources can be reduced and deforestation can be avoided. On the other, by saving the forests – which act as a carbon sink – and by replacing firewood with biogas technology, harmful greenhouse gas emissions can be reduced. It was estimated that the carbon emissions

saved by the three biogas digesters could amount to 74,500kg $CO_2$ per year. Due to the fact that the firewood has not yet been totally replaced and because of the delayed installation, this level of reduction has not yet been achieved.

In addition to preserving the forest and avoiding emissions, biogas plants can also have positive effects on soil fertility and food productivity due to the fact that slurry from the biogas systems is used as fertiliser for crop farming in the school gardens. To ensure that the manure meets the safety standards for crop production, monitoring must be carried out regularly.

## SOCIAL ISSUES

The biogas plants were built with the help of local technicians who were guided by experts from the technical team at IT Power Eastern Africa. This approach enabled the team to train and to transfer knowledge to the local technicians. These newly learned and developed skills serve both the technicians and their communities. Additionally, the introduction of biogas technology to the schools significantly reduces the indoor air pollution within the school kitchens.

## RESULTS & IMPACT

Three biogas plants have been constructed. Two plants at the Nakuru Boys High School were in operation by the end of the project. The school is already saving firewood and employs one person daily to maintain the biogas plant. While the construction and the initial feeding of the biogas plant at Nakuru Girls High School was complete by the end of the project phase, the piping still needed to be finished.

In addition to the construction of the biogas plants, 200 copies of a technical biogas manual for installers and a user manual were produced, printed and distributed.

## REPLICABILITY

There are around 3000 boarding schools and a further 3000 schools with kitchens in Kenya. All of them use firewood for cooking and could therefore potentially benefit from replacing this energy source with biogas technology. To avoid the problems that have led to most biogas plants in Kenya being dysfunctional, the training of technicians and users will have to be a key factor for the dissemination of the technology. It is absolutely necessary that the digesters are installed using the correct design, that installations are checked by qualified technicians and that the users know how to maintain their plant.

## LESSONS LEARNED

During the implementation of the biogas plants the project team - and the users - made several discoveries regarding the substrate supply, construction and materials used.

Because certain local areas experienced extensive droughts, livestock could not be kept at the dairy as there was insufficient fodder for the animals. This resulted in the need to purchase dung from a farmer to fill the digester for the first time. Problems with the gas pipeline occurred after a few months, so it is necessary that an experienced biogas plant engineer checks the plant after the construction phase is complete to ensure the durability of the technology.

A further problem was the stony subsoil at one construction site. IT Power eventually recommended changing the construction approach with the result that one of the biogas plants was built above ground.

On a final note, the biogas cooker that was originally constructed required later modifications. The cooker design should, therefore, be optimised right from the start for future projects.

Source: Final Report submitted to WISIONS by IT Power Eastern Africa

# BIOGAS STOVE CASE STUDY 4

## ENERGY SCHEMES FOR RURAL DEVELOPMENT: CLEAN COOKING FUEL IN INDIA

### PROJECT'S AIM

To develop and operate a sustainable rural demonstration project: a community dairy biogas enterprise.

### PROJECT DESCRIPTION

In India, millions of rural families lack basic amenities including access to clean and efficient cooking fuels. To address these problems and improve the situation of the rural poor, the Asian Regional Energy Initiative of the International Energy Initiative (IEI) implemented a project in the Indian village of Chikkana Devara Hatti (238 inhabitants). The project aimed to demonstrate that a dairy biogas model, operated as a village-based multi-functional enterprise, could boost rural development. The enterprise consists of a dairy, for income and fuel, and associated household biogas supply systems that replace the existing traditional biomass stoves.

The dairy employs local people and the waste produced is used to fuel the biogas generation plant that delivers energy and fertiliser. The milk from the dairy is sold, supporting the operation financially. Before the biogas digesters were constructed, the rural families' energy requirements were estimated. As a result it was decided to build eight biogas digesters, which are shared between families. The villagers belong to a traditional shepherd tribe, called "Kadu Golla", which is in need of socio-economic assistance.

The biogas is supplied to all homes in the village and has replaced traditional biomass stoves. This access to modern energy services has led to a reduction in the time spent gathering fuel and has also reduced both indoor pollution and carbon emissions. To ensure the democratic involvement of all families, a village assembly was formed in which every household is represented by one member.

**Location:**
Chikkana Devara Hatti, Karnataka, India

**Costs:**
Total: € 90,646
WISIONS financial support: € 67,000

**$CO_2$ Reduction:**
456 t/year ($CO_2$e)

**Partners Involved:**
Regional Energy Initiative - Asia,
International Energy Initiative (IEI)

**Duration:**
01/2007 – 05/2008

**Webpage:**
www.iei-asia.org

### TECHNOLOGY, OPERATIONS AND MAINTENANCE

Establishing the dairy involved three main components: the construction of the buildings, the selection and purchase of cows from local farms and the arrangements for the daily operation of the enterprise. The dairy buildings can house a total of 112 cows, a water facility and a small office.

Local people were employed and trained to undertake the work. To ensure responsibility, each employee was assigned a specific set of tasks and a retired teacher was appointed as a supervisor. Four months after the dairy construction started, work began on the biogas plants.

The biogas requirement per family was estimated on the basis of the present biomass use and doubled to provide for increases in both residents and gas demand. Based on the pattern in which the houses are situated in the village, 8 biogas plants (6 of 8m3 capacity and 2 of 10m3 capacity) were installed. The cylindrical pit floating drum biogas digester model was chosen because it requires minimal maintenance.

The construction of each biogas plant involved excavation works, masonry lining, fabrication and installation of the guide frame and gas holder, construction of the inlet tank and effluent outlet tank adjacent to each digester pit, and the piping connections for retrieval of the gas.

The guide frames and the gasholders were fabricated outside the village. The local population was involved in the construction work but additional skilled labour had to be hired. One employee was trained in the operation and maintenance of each digester. Dung from the cattle sheds is collected regularly during the day and stored in large covered bins.

To distribute the biogas, mini-grid piping systems were installed, connecting each digester with a group of households. A stop-valve is used to regulate the gas flow. Each kitchen was provided with a double-burner stainless steel stove to use the biogas as clean cooking fuel.

### FINANCIAL ISSUES AND MANAGEMENT

The plan was for the project to be economically feasible, based on the expected operational outflows and inflows at market prices. The expected payback time for the basic construction costs (excluding management and monitoring) with/without interest (5%) was 4.4/3.7 years. An accounting system was established to manage the enterprise and the supervisor at the office records the daily inflows and outflows. During the project, the IEI undertook weekly verification and electronic recording of the relevant details. In addition, daily communication between

the supervisor and IEI ensured that any problems could be dealt rapidly.

At the end of the project, the operating costs were higher than expected due to increases in the price of grain and, therefore, of cattle-feed. The team handled this problem by replacing packaged feed with less expensive natural fodder. This replacement had to take place gradually because of the time required for the fodder crops to be grown and harvested.

## ENVIRONMENTAL ISSUES

Biogas is preferable to traditional biomass stoves/fuel not only for its fuel efficiency, but also because it generates much lower GHG emissions. This project, which involved 238 inhabitants (47 households), resulted in a reduction in GHG emissions of around 456 t per year ($CO_2$ equivalent). As the project was intended to be a demonstration project for further replication, the total emissions reduction will depend on the overall number of homes that become involved.

## SOCIAL ISSUES

The involvement of all the families and the co-operative operating structure were major success factors. The dairy farm and the biogas plants provide steady employment in an area where people are generally poorly educated and daily wages are uncertain. Employment, income and access to clean cooking fuels offer a rare opportunity to improve the village population's living conditions.

It has been observed that other projects have been less successful in terms of public participation because of perceived inequalities (e.g. only those owning cattle had to supply dung), or because they have been restrictive on the basis of affordability (e.g. only those households who could afford it had the technology).

The provision of clean cooking fuel reduces the time needed for fuelwood collection and also has positive health effects. Gas is provided during the common cooking times in the village (usually 3 hours in the morning and 1.5 hours in the evening, but adjusted according to the mutual convenience of the families sharing each plant).

## RESULTS & IMPACT

The project enabled all families in the village, regardless of income or social strata, to have access to clean cooking fuel, based on the demand and suggestions from the users. The users were very satisfied with this service. Furthermore, employment and income opportunities were created within the dairy and for the operation and maintenance of the biogas plants.

## REPLICABILITY

The replication potential of the project in India is high, as about 85% of rural homes still depend on biomass as cooking fuel. It is important to take local circumstances into account when establishing such a project. In order to increase interest in the model, the project has been promoted through the local media. However, the initial funding will remain a critical issue for new start-ups. In the future, financial support through the CDM mechanism could support larger-scale replication of the biogas rural energy development model.

## LESSONS LEARNED

Several factors should be noted when considering future projects. The construction and the training (technical and management) took much longer than predicted. Furthermore it would have been more efficient to begin constructing the cattle-sheds and biogas plants simultaneously, rather than consecutively; the cattle could then have been purchased in groups as each shed was completed, and corresponding waste-based biogas generation and distribution could have progressed in segments across the village. For large-scale replication, it might be preferable to have the option of some larger burner biogas stoves for community use, as the design used is only suitable for general household cooking. On a financial note, future projects should include a contingency allowance to help absorb external shocks such as price increases in basic construction materials. Furthermore, the financial balance of a project would be more sustainable if the input flows, such as fodder, were purchased locally and were, therefore, unaffected by national or global price increases. This type of local relationship also reinforces the social and environmental benefits.

Source: Final Report submitted to WISIONS by Regional Energy Initiative - Asia

# SOLAR COOKER

Solar cookers are devices that are used to prepare food by (directly) harnessing solar radiation. The technology is most appropriate in sunny and dry regions with sufficient levels of solar radiation (but it does also have followers in less sunny countries). However, in order to ensure the successful implementation of this technology, local needs, cooking habits and social conditions must be taken into account.

Many different models of solar cookers with hundreds of variations exist, but most follow the same basic principles. The three most common types of solar cookers are depicted by Figure 2 and main characteristics are listed in Table 2.

- Solar Concentrator

The basic principle consists of a reflecting material, such as aluminium facets in the form of a parabolic mirror, which reflects bundled solar radiation directly onto the cooking pot [9]. The simple versions require frequent adjustment to track the path of the sun (every 25 to 30 minutes), are sensitive to wind and need constant supervision for safe operation [10]. Nevertheless, parabolic cookers have a longer lifespan compared to other solar cooker models and they are, in general, water-resistant.

One type of solar concentrator that is widely used is the so-called 'Scheffler' collector (named after its developer). The cooker is designed in such a way that cooking can take place inside the house while the concentrating reflector is situated outside in the sun, as illustrated by Figure 3. The design allows the reflection surface to change shape to adapt to different angles of the sunlight during the different seasons. The Scheffler reflectors can be constructed in any size, from 2m² for domestic cookers to 60m² for large industrial applications.

- Solar Box

The most basic version of a box cooker consists of an open-topped insulated box that is coloured black on the inside, with one or two pieces of glass or transparent plastic covering the top of the cooker. It can reach moderate to high temperatures, with maximum temperatures of about 180°C. This is not as hot as traditional stoves and if food with high moisture content is cooked the temperatures do not usually exceed 130°C. On the other hand, box cookers do not usually have to be realigned according to the position of the sun while cooking and can deal better with fluctuations in solar radiation [9].

- Solar Panel

Solar Panel cookers integrate elements of both box and parabolic cookers. A metallised cardboard reflector is folded into a bowl or multi-facet shape, concentrating the sunlight onto a dark coloured pot, which is situated in a transparent plastic bag that acts as a heat trap. It reaches low to moderate temperatures, high enough to purify drinking water or to cook grain such as rice.

Table 2. Solar cooker
Sources: [9,10,11,12]

| Type | Technical and economic issues | Cooking conditions |
|---|---|---|
| **Solar Concentrators** | • Reflecting material in parabolic form<br>• Expertise required for construction<br>• Import of reflecting material necessary<br>• Costs vary, start at € 40 for 1,5m²<br>• Sensitive to wind and need supervision for safe operation | • High temperature (250°C), as fast as conventional cookers<br>• Can prepare all types of food (baking difficult)<br>• Need to be adjusted to the sun<br>• Cooking outside in standing position, Exposure to sun, dust and wind |
| *Scheffler concentrator* | • Flexible parabolic reflector concentrating to fixed focal point with automatic adjustment<br>• High costs, starting at € 500 for 8m²<br>• Decoupling of cooking and solar concentration possible | • Cooking inside house possible<br>• Large scale processing possible<br>• Automatic adjustment to the sun |
| **Box cooker** | • Various box material possible (simple to high cost)<br>• Costs start at € 30 and can go up to a few hundred EUR, depending on material and quality | • Low temperature (100° - 180°C)<br>• Only little adjustment to the sun necessary<br>• Protected against wind and dust<br>• Cooking and Baking possible<br>• Can cook multiple pots |
| **Panel cooker** | • Easy to construct with local material and self-made models possible<br>• Can be folded or collapsed<br>• Low-cost (from € 2-10 for cardboard models)<br>• Often not waterproofed and sensitive to wind | • Cooking of 1 pot only<br>• Low temperature, longer cooking times<br>• Only little adjustment to the sun needed<br>• Cooking on the ground or elevated possible |

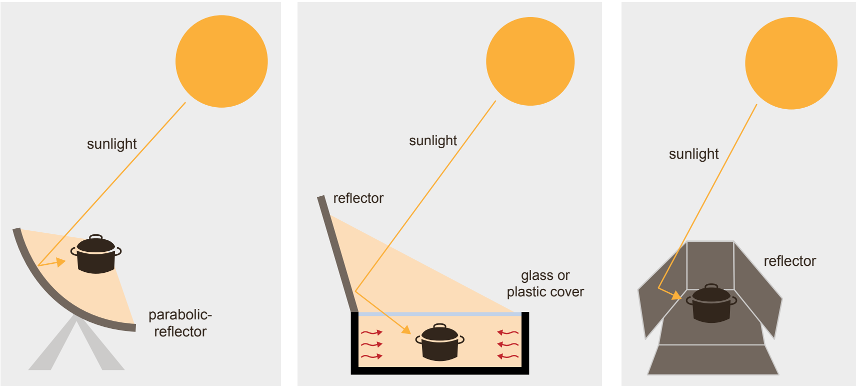



Figure 2. Most common types of solar cookers: Solar concentrator, Solar box, Solar Panel

Figure 3. Example of Scheffler collector

## GLOBAL SUSTAINABLE ENERGY SUPPLY

Solar cookers can contribute to reducing the use of unsustainable cooking fuels, like firewood or LPG. About 85% of countries in Africa, the Americas and Oceania have the appropriate conditions for solar cooking [9]. In Asia as well, there are a lot of suitable regions. However, there are no countries where solar cookers can be used as a stand-alone system without any alternative energy source. It is recommended to use them as part of an integrated cooking system, e.g. in combination with improved biomass stoves or biogas.

## MILLENNIUM DEVELOPMENT GOALS

The use of solar cookers can contribute to almost all the United Nations Millennium Development Goals (MDGs). They offer access to a clean and free energy source to meet the basic need of food preparation.

However, the technology is not suitable as a single solution. It should be used to complement other cooking technologies. Because of this, thorough assessment of current cooking practices and actual requirements of potential users are recommended before designing strategies for the diffusion of solar cookers.

## SOCIAL ISSUES

In areas with sufficient solar radiation the use of solar cookers can help to make significant improvements to the living conditions of poor households. However, the benefits can only be achieved if the potential user accepts the new cooker technology and uses it regularly.

The best approach is to adapt the technology to local conditions in such a way that traditional cooking habits have to be changed as little as possible.

Gaining acceptance for the technology has been shown to be challenging in many cases. Some notable issues are:

- Cooking outdoors, exposed to the sun, wind and dust is not a common practice.
- Solar cookers can only be used when the sun is shining, which might not coincide with the usual time that the people have their warm meals.
- The availability of a sunny space is often a problem in urban contexts.

The fact that a solar cooker cannot be used as a stand-alone alternative can discourage potential users from investing. However, studies of previous projects show that improvements in both equipment design and the training of users can significantly increase the acceptance of the technology [11].

## DEVELOPMENT STATUS AND PROSPECTS

Over the last few decades a number of solar cooker designs have been created and modified, often by committed individuals who are personally motivated to improve the technology. The performance of the different types varies widely and only a few high quality products exist.

The poor quality of the cookers has often been a barrier to the acceptance of the technology and has even created an associated negative image; therefore the introduction of quality standards is regarded as essential for the successful broader dissemination in the future. On the other hand, this brings into question whether or not it is advisable to promote very low-cost models.

In regions with no alternative energy source and where solar cooking fits in with local cooking habits, e.g. in the highlands of Tibet or the Altiplano in South America, solar cookers have become generally accepted and are now widely used by the local population [12]. In areas where solar cookers are not easily compatible with cultural cooking practices, such as in India and many regions of Africa, they do not, as yet, compete with traditional cooking methods.

# SOLAR COOKER CASE STUDY 5

## USING CARBON CREDITS TO BENEFIT ANDEAN SOLAR

### PROJECT'S AIM

To use carbon credits to make solar applications affordable, improving the living standards in local villages.

### PROJECT DESCRIPTION

Puna, Argentina, is one of the most deprived areas in the remote Andes. The main energy source is biomass, collected from the sparsely vegetated high plateau, which leads to desertification, erosion and loss of biodiversity.

Solar applications are a proven technology in the "Solar Andean Villages", due to their introduction under previous programmes. The technology has become well accepted by the local population but, unfortunately, most families cannot afford it without financial aid.

To overcome this problem, Fundación EcoAndina, with several partners, initiated this project with the aim of establishing sustainable financing using carbon credits. The major focus of the project was to develop and test a measuring device and to gain and transfer knowledge about handling the complex carbon market opportunities.

Solar cookers, equipped with the new measuring device, were sold to 40 families. The data collected over time was used to develop a baseline study to determine the $CO_2$ emission savings.

### TECHNOLOGY AND MEASUREMENTS

Two technologies were implemented during the project. Although the region was already familiar with solar cookers, the SolCoDat device was a newly-developed technology. It was designed to measure the direct solar insolation levels in order to calculate the energy input to each individual solar cooker and the daily usage hours.

The SolCoDat had unexpected teething problems. Technical difficulties occurred with the data read-out and with resetting the devices, and some devices recorded incorrect data and time. Furthermore, the wide variations in air temperature caused problems.

Another critical issue was that the timeframe did not account for the fact that the families would be absent during the rainy season between January and March, meaning that no measurements could be taken during that time.

However, continuous field tests helped to identify the various technical problems and facilitated a continual improvement process. As a result, by the end of the project the monitoring technology was fit for purpose.

### FINANCIAL ISSUES AND MANAGEMENT

To make the solar cookers affordable for local families, payment by instalment was offered and carbon credit payouts (as much as € 15 - € 20 per year) were promised.

The project team was responsible for the measurements, as well as for the paperwork and carbon credit verification. They also managed the profits from selling the generated carbon credits to the company GreenStream, who sold these on the voluntary market for greenhouse gas reduction certificates. The profits were distributed equally to those families who purchased solar cookers. During the project each user received three payments of around € 8, regardless of their individual usage. Once several payouts had been made and the project attracted public attention, the project team faced a sudden increase in demand for the solar cookers, which was promising for the future expansion and dissemination of the project concept.

### RESULTS & REPLICABILITY

The project demonstrated how renewable energy projects in developing countries could be financed by carbon credits. Solar cookers were made affordable to the local population and, simultaneously, the technology became economically feasible. The 40 families who now own a solar cooker benefit from access to clean and sustainable energy for cooking.

The introduction of solar cookers helped to reduce both $CO_2$ emissions and the demand for fuel wood amongst the participating families. On average each solar cooker saves 3.8t $CO_2$ per year. In total 190t $CO_2$ and 200t of biomass can be saved annually due to the project activity.

The project design and technology have good potential for replication. Technically the concept is suitable for regions that lack access to modern energy services and have appropriate levels of solar insolation. Economically, linking the global carbon market to regional solar power markets offers a solution to the recurring problem of how to make renewable energy technology affordable and economically feasible.

Source: Final Report submitted to WISIONS by Fundación EcoAndina

# SOLAR COOKER CASE STUDY 6

## SHEA NUT BUTTER PRODUCTION IN BURKINA FASO

### PROJECT'S AIM

To apply and demonstrate different solar technologies in traditional food processing.

### PROJECT DESCRIPTION

The Shea nut butter project is located in Tiakane, a village in the South of Burkina Faso.

It was part of the "Solar Food Processing project", which was supported by SEPS in three consecutive phases from 2006 - 2009. The International Solar Energy Society (ISES) implemented the project with the purpose of promoting the solar food processing and production market. The first phase saw the establishment of the network and an internet platform (see solarfood.org) and the aim of the second phase was to actively support projects with potential. Together with partners in four different countries, existing solar food technologies were further applied, tested, evaluated and improved. The aim was to obtain high quality standards in sustainable food production and to promote this economical and ecologically viable technology. At the same time, the intention was that specialists would produce the technology locally, which is why technical training and marketing strategies were also integrated.

The Shea nut butter project was implemented by the local partner company ISOMET, Innovation en Solaire et Métallique, who were also responsible for the construction and installation of the solar technology. When the installation was complete, in July 2007, the women of Tiakane were shown how to use the system.

### TECHNOLOGY AND OPERATION

The solar Shea nut butter unit consists of two Scheffler concentrators with a kitchen house and 12 solar box cookers.

The solar production of Shea nut butter does not differ from the traditional process, making it easy for the women to adopt. Instead of firewood, solar energy is used as the heat source. Organising the production was a major challenge as families traditionally produce the butter on their own, whereas the solar installation is a community resource centrally located in the village.

There are four processing phases. The first step is to collect the nuts during May to July. After that the solar concentrators are used to boil the nuts on sunny days. The sterilised nuts are spread on the ground for drying and then stored in the kitchen house.

The next step is to crush and roast the nuts, which can either be done in the solar box oven or by using the Scheffler concentrators. The latter is faster and the women are keen on this method, although the heat can lead to burnt fragments. Roasting the nuts in the solar ovens has advantages in terms of quality, such as higher purity of the oil and no combustion, but it takes more time and requires more organisation.

The only step that does not use solar energy is the milling of the roasted nuts to produce the paste, which is done using a diesel mill. After that, the paste is churned and the oil is separated from the butter. The liquid Shea butter must then be boiled to evaporate the water content and purify the product; this is done using the solar concentrators. A major advantage of the solar process in comparison with the traditional process is that it does not produce smoke, soot or aromas that can adversely affect the quality of the oil.

The day after this final stage in the process, the Shea nut butter can be sold at the local market.

### RESULTS & LESSONS LEARNED

The results in Burkina Faso are very promising. Initial tests have proven that the end product is of a better quality than the traditional butter. It is very important to support the women involved and to train them in the technology and its maintenance, as they play a key role when it comes to the introduction of a new technology.

In Tiakane around 300kg of solar Shea nut butter was produced, 80% of which was sold at the local market and 20% of which was taken to Germany for test selling. The women could produce more (about 1000 kg) if there was the demand.

Overall, the project demonstrated that it is very difficult to guarantee a consistently high quality product (e.g. for export) and that the marketing requires much more effort than expected.

In 2011 the solar production of Shea nut butter is still underway and the partners who are currently involved (ULOG and ISOMET) are trying to disseminate the technology more widely (see www.solarfood.de).

Source: Final Technical Report: Solar Food Processing & Conservation (Phase II) submitted to WISIONS by ISES

# SOLAR OVEN

Solar ovens are devices that use solar radiation as their energy source for baking; they are a sub-category of solar cookers. The food is placed in a box that has, preferably, an even heat distribution. The box can be heated by direct sunlight entering through one or two windows (as in the case of box cookers) or by sunlight concentrated by a parabolic reflector. The term solar oven is often used synonymously with solar cooker and solar box cooker.

The simplest solar oven technology is very similar to a solar box cooker. Box cookers prove that the baking of bread, cakes and biscuits can be done at lower temperatures, i.e. typically at 130°C, for longer cooking times. However, some recipes, like pizza, are not successful at such low temperatures.

Parabolic solar ovens use more advanced technologies and can reach higher temperatures (over 200°C); these are therefore better suited for standard baking processes. In order to achieve the higher temperatures, the parabolic solar focuses the sunlight onto a receiver in a specially constructed baking oven, as illustrated by Figure 4. Such solar ovens can reach temperatures of up to 300°C [13].

The key limitations of most solar ovens are their inability to store enough energy for cloudy weather conditions, night or early morning baking and the longer baking times required [14]. Solar baking in the rainy season and in areas with limited sun radiation is, therefore, restricted. For commercial bakeries, hybrid techniques are available that use e.g. gas or biomass when there is not sufficient solar radiation for baking.

## GLOBAL SUSTAINABLE ENERGY SUPPLY

Most of the energy consumed by households in the developing world is used for food preparation and heating. Using solar energy for cooking and baking can reduce the unsustainable use of fuels such as charcoal and fossil fuels or firewood that is harvested non-sustainably. With increasing deforestation and a growing population, by 2050 firewood will become an even scarcer resource. Solar ovens are, therefore, a highly suitable technology for using in remote areas with wood fuel shortages.

## MILLENNIUM DEVELOPMENT GOALS

Solar ovens offer an urgently needed clean and cheap alternative to traditional fuels (which are in diminishing supply) for baking. The technology is particularly appropriate for remote areas where no baking is possible with simple cookers, such as the 3-stone model, and where bread needs to be purchased from urban settlements. For these reasons, dissemination of the technology on both a small and large scale can contribute towards reaching the MDGs, making fresh bread affordable for poor households and preventing the unhealthy use of firewood.

## DEVELOPMENT STATUS AND PROSPECTS

Solar ovens are used in numerous countries but, unfortunately, there are no statistics available that relate solely to solar baking. Solar cookers and solar ovens are usually accounted for in one category. The number of solar cookers (including solar ovens) in use globally is estimated to be around 1.5 million [12].

While the use of box cookers for slow baking is commonplace, large-scale commercial solar bakeries are still limited to a small number of pilot projects. The next stage is to analyse the experiences gained in order to develop a long lasting, efficient and user-friendly oven, which has the option to use a second energy source on cloudy days or during the rainy season. The alternative energy source should also be, preferably, environmentally friendly.

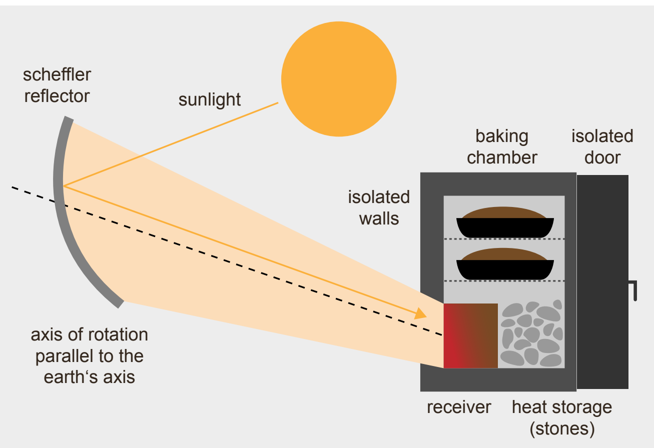
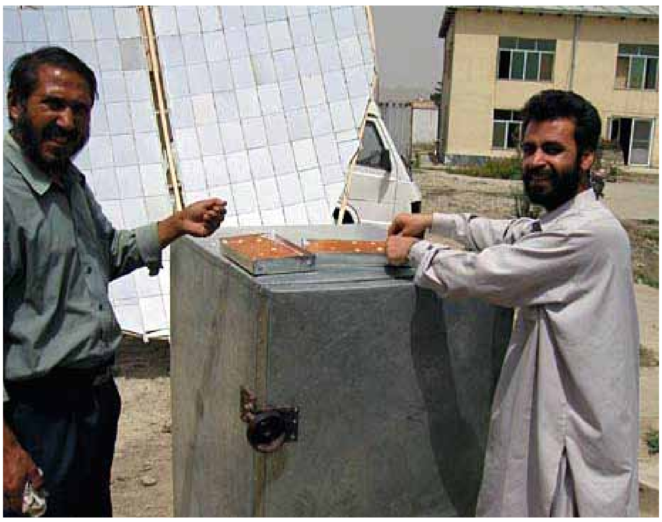



Figure 4. Schematic view of a solar oven using a Scheffler concentrator



# SOLAR OVEN CASE STUDY 7

## SUSTAINABLE SOLAR BAKERIES IN CAMEROON

### PROJECT'S AIM

To introduce environmental friendly solar bakeries and provide opportunities for woman to generate their own income.

### PROJECT DESCRIPTION

In Cameroon only 1% of bakeries are located in rural areas. This means that bread must travel long distances to reach rural regions and rural people have to pay higher prices for bakery products of lower quality. Currently, charcoal-fuelled ovens are used for most baking in Cameroon. During the combustion process, harmful greenhouse gases are released into the atmosphere with known detrimental environmental effects.

The project addressed these problems by establishing a self-sustaining bakery enterprise in the rural area of Buea, using solar power as its energy source. Furthermore, the solar bakery creates employment for women who run the bakery and prepare, bake, sell, and deliver the goods.

The village of Nguti was identified as a suitable location and a detailed business plan was developed. The next step was to select motivated women, who were trained by local experts to operate and manage the bakery business. UNEP/Wuppertal Institute Collaborating Centre on Sustainable Consumption and Production (CSCP) initiated the project, in cooperation with the local partner Nature Cameroon.

### TECHNOLOGY AND OPERATIONS

The solar oven was manufactured in the USA. It is designed to produce bakery products in large quantities within a short period of time. The oven reaches temperatures of about 260°C using only solar power. In order to concentrate the solar radiation, rugged aluminum panels are used as heat collectors. The captured energy is then directed to the oven container where the goods are baked. The only ongoing maintenance required to keep the solar oven functional is regular greasing of the rod that is used to angle the oven to track the sun. In areas with a lot of dust the reflector and glass may also need to be cleaned several times a day to ensure high performance.

### FINANCIAL ISSUES AND MANAGEMENT

Procuring the solar oven resulted in high initial costs of about €10,000. Once the bakery started, its operation became economically viable. As the project partners were aware that the high initial costs would affect the potential for project expansion, they planned to establish a revolving fund. The aim was to save a portion of the revenue generated from sales and to reinvest this money to set up additional bakeries. However, by the time that the project officially ended this fund had not been established.

### RESULTS & LESSONS LEARNED

Since 2009, the solar oven has provided 200 rural families with fresh bread at a lower price. Furthermore, employment was created for between 7 and 10 motivated and skilled women, who now have the opportunity to earn their own income and improve their families' living standards. Additionally, the bread that is produced provides an additional food staple at an affordable price.

During the project implementation phase, the main barrier to progress was poor communication between the partners due to inadequate connectivity, which resulted in the implementation progressing slowly. Secondly, it took a long time to get a tax exemption for the import of the oven.

In theory, a solar bakery using this technology can provide bakery products for up to 250 families. With Cameroon's current rural population, there is the theoretical potential to install a few thousand rural sun bakeries. The major barrier to the widespread dissemination of the technology is clearly the high initial cost for the imported solar ovens.

For future projects one important factor is the need to raise awareness amongst stakeholders, such as policy makers and educational institutions, to ensure their engagement and involvement. Equally important are follow up activities, which can help to sustain the project, support replication in other areas and help to develop entrepreneurial sprit in the local communities.

Source: Final Report submitted to WISIONS by CSCP

# SOLAR OVEN CASE STUDY 8

## THE SOLAR PROJECT GAMBIA – SOLAR BAKERY, WORKSHOP AND RESTAURANT

### PROJECT'S AIM

To promote solar baking and cooking in Gambia and establish an economically sustainable solar food business.

### PROJECT DESCRIPTION

The SolarProjectGambia (SPG) started in January 2006 with the aim of promoting and disseminating solar food processing technologies within Gambia. The climate is favourable for solar technology and the development of sustainable food processing is necessary due to the overuse of fuelwood and significant deforestation. Once imported solar stoves had found approval in Gambia, the first priority was to produce solar stoves locally. The idea was to create a workshop where solar cookers could be produced at a lower cost, making them affordable for the locals. As well as the workshop, it was decided to set up a solar bakery and, subsequently, a solar restaurant.

As the Gambian project met the necessary prerequisites, it was selected as a partner of the WISIONS Solar Food Processing project (see Case Study 6, page 20). A business plan was set up in cooperation with ISES for the further development of the project.

### TECHNOLOGY AND MAINTENANCE

In January 2007, an expert from ISES trained 5 craftsmen in solar stove and drier production. As a result they can now produce two sizes of solar stoves (solar box cookers) and a solar tunnel dryer model. Once the first of these appliances had been produced, the solar bakery was constructed and the products developed and tested.

The bakery produces many different kinds of pastries, cakes and sweets and savouries such as pizza or meat and fish pie. Eight solar stoves are used daily. During the project phase the bakery only operated on sunny days and not during a heavy rainy season.

The third stage was to open the solar restaurant in April 2007, where products from the bakery and lunch and cool drinks are sold. A PV solar system is used to supply electricity, which is particularly useful during power cuts. Due to public solar cooking demonstrations and the sale of solar baked products, the Solar Project Gambia has become recognised across the region and country.

### RESULTS & LESSONS LEARNED

By the end of the SEPS funded project phase (2007–2008), a small solar business had become established in Gambia. A workshop for the production of solar stoves and solar driers, a solar bakery and a solar restaurant were up and running. Craftsmen were trained to fulfil minimum quality standards for the Gambian market. In 2008 (during the SEPS project phase), 6 people were employed by the SPG.

The bakery products are regularly sold on the street and are well accepted by local customers. Tourists also visit the project, not only to taste solar food but also to see how the project operates. The solar restaurant attracts the attention of passers by and offers the opportunity to inform customers about deforestation and its consequences.

Unfortunately the baking production was interrupted because of a heavy rainy season and it was not possible to generate enough income to cover the costs. After the rains, however, the bakery moved to a more appropriate location and its production capacity was increased. Other obstacles faced were illiteracy, lack of technical skills and the need for professional marketing and long term planning within the team. The lack of education adversely affected the project: it was particularly difficult to train the carpenters to produce good quality products. Further training and planning is very important to keep the project running.

It has also been difficult to convince the local population of the importance of buying a solar cooker for household use. Although they like the idea of solar cooking/baking, they are still reluctant to invest money in this new technology. The price of a solar box cooker is about 4500 dalasi, which is about 1.5 – 3 times the monthly salary of a normal worker.

In 2011 the project is still running successfully under the name "Solar Project Tiloo" (see www.tiloo.ch).

Source: Final Technical Report: Solar Food Processing & Conservation (Phase II) submitted to WISIONS by ISES

# SOLAR DRYER

Using the power of the sun to preserve food and other agricultural products has been practiced for centuries. In the traditional way crops are dried directly in the sun under the open sky. The major disadvantage of this traditional method is that the goods are exposed to dust, animals, insects, wind and moisture. In addition, the results depend on good weather conditions [15].

Modern solar dryers are more efficient, hygienic and keep the crops safe from damage and insects. The most advanced designs allow for controlling drying parameters such as moisture content, air temperature, humidity and airflow rate. Adequate drying helps to preserve the flavour, texture and colour of the food, which leads to a better quality product [16]. Many different models and designs of solar dryers exist, but all follow the same basic principles and consist of three main components:

1. a drying chamber in which the food is laid out;
2. a solar collector that heats the air;
3. some type of airflow system.

Depending on the form of air circulation (natural or forced convection) and the way that the solar radiation is used (direct heating of air together with the food or indirect heating of air in separate drying chamber) solar driers can be classified in different categories, as described by Table 3 and illustrated by Figures 5 and 6.

## GLOBAL SUSTAINABLE ENERGY SUPPLY

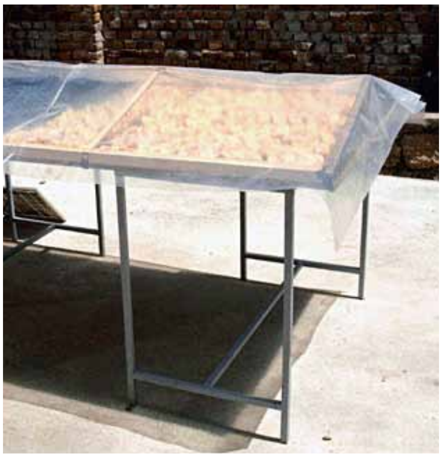
Solar crop drying technologies can replace only moderate amounts of fuel wood or fossil fuels currently used in developing countries for the process of crop drying [17]. However, the technology has significant potential for wider decentralised application, especially in areas that do not currently use modern drying technologies and which suffer from a high proportion of postharvest losses through food spoilage.

## MILLENNIUM DEVELOPMENT GOALS

Using solar energy for drying agricultural crops can contribute to meeting the MDG target of reducing the number of people who live in extreme poverty and hunger. By using a cheap, easily manageable and appropriate technology for food processing, post-harvest losses of fruit and vegetables can be significantly reduced, which can help to increase food security. Additionally, solar dryers can create employment and local income-generating opportunities, especially in rural areas.

Table 3. Types of solar dryers
Sources: Sources: [15,28,29,30]

| **Use of solar radiation** / **Air Circulation** | **Direct use of solar radiation (Food inside the collector)**<br>• Applicable for food where the colour change caused by the sun is acceptable (e.g. raisins, grains and coffee)<br>• Limited control of temperature and drying rate | **Indirect use of solar radiation (Food in separate drying chamber)**<br>• Separate collectors and drying chamber<br>• More expensive and complex<br>• Food is not exposed to direct solar radiation which reduces the loss of colour and vitamins |
|---|---|---|
| **Natural Convection**<br>• Low cost<br>• Easy to operate<br>• Long drying periods<br>• Limited control of air flow and temperature<br>• Suitable for small models → only small quantities can be dried at a time | *Direct natural convection solar dryers*<br>• Can be as simple as a box covered with plastic to trap the sun's heat (needs air-flow).<br>• Suitable for small-scale application.<br>***Examples:***<br>Tent dryer, Cabinet dryer, Brace dryer | *Indirect natural convection solar dryers*<br>***Examples:***<br>Tent dryer, Cabinet dryer, Brace dryer |
| **Forced Air Circulation**<br>• Airflow provided by an electric fan<br>• Most widely used dryer type<br>• More efficient and faster drying rates due to high airflow rates<br>• Better temperature control high capital and operating costs | *Direct forced circulation solar dryers*<br>• Drying time can be reduced substantially.<br>• Suitable for small businesses<br>• Commercially available.<br>***Example:***<br>Tunnel dryer | *Indirect forced circulation solar dryers*<br>• Suitable for large quantities and high quality products.<br>• Industrial & commercial applications<br>***Example:***<br>Dryer of Oekozentrum L |



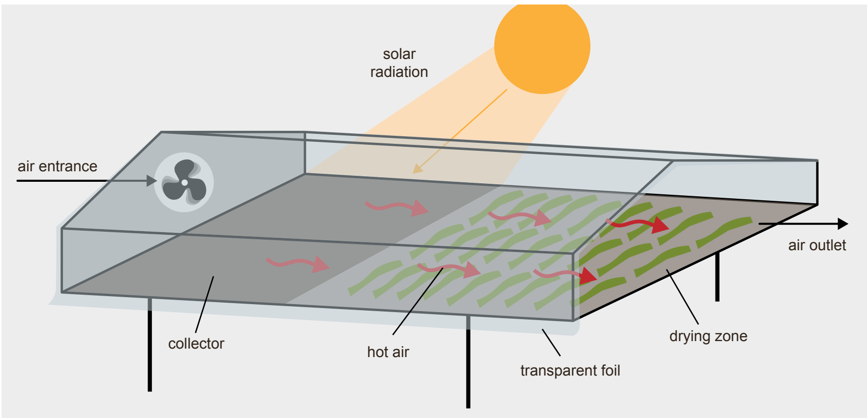



Figure 5. Principle of a tunnel dryer

## SOCIAL ISSUES

The implementation and use of modern solar drying technologies can have positive socio-economic impacts on food security and local income generation. However, to achieve these impacts, a functional value chain as well as local acceptance is essential.

For solar drying to provide sustainable returns, careful development and placement of the appropriate technology in a fully integrated value chain stretching from producer to consumer is necessary [18].

To date, solar dryers have found very little acceptance at local level. One crucial factor is the development of a (stable) demand for dried products. It is not easy or straightforward to promote the consumption of dried fruits and vegetables in regions where fresh produce is available all year round. If the consumption of dried foods is not already common, it will be more difficult to gain acceptance of solar dried food and, as a result, of solar dryers.

Export markets may provide interesting alternatives. The demand for dried fruit is increasing on the international market due to the organic food and health movement. However, at the same time, the high quality standards and restrictions on food imports are often a big hurdle for producers from developing countries.

## DEVELOPMENT STATUS AND PROSPECTS

While the positive aspects of solar drying mean that developing the technology is popular with NGOs and researchers, only a moderate number of solar drying units are currently in use globally.

Large-scale commercial solar dryers have proved to be successful, but still rank behind conventional dryers in terms of market penetration. On the other hand, the quality and efficiency of small-scale dryers is often poor, which is why they are not yet economically feasible.

Nevertheless, the future could be bright for solar dryers if the right market conditions exist and the appropriate technology is used. To promote the broader dissemination of the technology, the implementation of basic quality standards would be helpful. Local needs and conditions will also have to be taken into account when further developing the appliances.

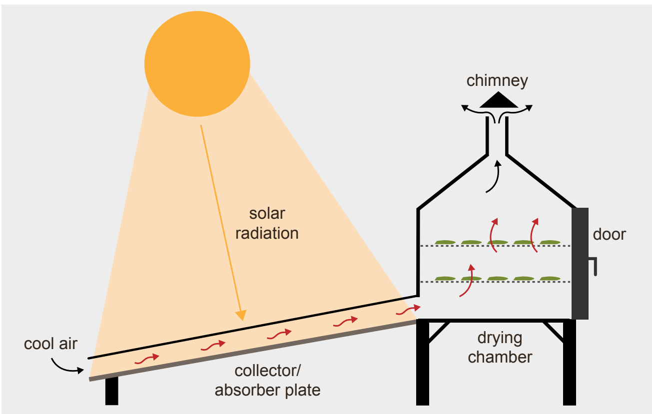



Figure 6. Principle of an indirect solar dryer

# SOLAR DRYER CASE STUDY 9

## MODERN SOLAR DRYING IN AFGHANISTAN

### PROJECT'S AIM

To test small solar tunnel dryers, develop capacity building and introduce high quality solar dried products.

### PROJECT DESCRIPTION

The climate in Afghanistan is very dry, so the traditional method of preserving fruit and vegetables is to dry them outside. Usually the produce is sliced and then laid out on the flat rooftops until bone-dry. The drawback is that the dust in the air and the clay from the roof sticks to the produce and, in addition, there is no protection from birds or insects.

The project, which was implemented by the Afghan Bedmoschk Solar Center, aimed to produce higher quality dried foods by using modern solar tunnel dryers. As part of the ISES Solar Food Processing project (see Case Study 6, page 20) the objective was to promote the technology in Afghanistan and to develop a small solar food business.

### TECHNOLOGY AND MAINTENANCE

To test the technology under Afghan conditions, a model solar tunnel dryer was developed that is 2m x 1m in size – a smaller version of the 20m x 2m Hohenheim Solar Tunnel Dryer. The advantage of this small – but equally functional model – is that it allows farmers to test and evaluate the technology before investing their money and time.

The summer air is very dry in Afghanistan. Solar driers cannot speed up the drying process; their benefit lies in producing a higher quality end product compared to traditional methods.

6 solar tunnels driers were installed at the SFP workshop and these work like solar air collectors. A computer fan is driven by a 5W solar panel to force the hot and moist air out of the drier.

Start-up packages were offered to interested parties. The package was well received and included the small dryer, training that covered set-up, use and maintenance, packaging, storing and marketing and a set of packaging materials. A training curriculum in German and Persian was specially developed.

It takes around 3 to 5 days to reduce the weight of the produce from 7 kg to between 0.4 and 1 kg (e.g. for apricots or tomatoes). The air in Kabul is very polluted, so drying times would be slightly lower in rural areas. 200g packages were produced using locally available clear plastic bags. More durable plastic bags were imported and provided in the training sessions. Attractive labels in Dari and English were designed, which is important for selling products to foreigners.

In addition to the driers, Scheffler reflectors were installed for producing marmalade and jams. The same technology is used for baking bread and cake in specially designed ovens.

### RESULTS & LESSONS LEARNED

Taking into account the political situation and security difficulties in Afghanistan, the results were positive. During the official project time, 42 model dryers were installed and training provided. There is real interest and potential for solar food processing in Afghanistan, because of the sunny climate, available raw produce and the potential market. Due to the tense political situation it was not possible to undertake a proper marketing campaign.

The technology is very useful for farmers who are in the business of drying fruit and vegetables. The high quality end product (cleaner and of a better colour) and the professional packaging demonstrated the advantages of modern solar drying.

However, the price of the solar dried vegetables was higher then acceptable for general sale in Kabul. The marketing must, therefore, target the high-end e.g. supermarkets and places where wealthier people and foreigners shop.

Economic feasibility and further dissemination could be achieved through larger scale production or direct use and marketing in rural areas. As the value per kilogram harvest increases, the transport costs could be proportionally reduced, leading to higher earnings for the farmers.

However, it was clear by the end of the project that the cost of the small driers was too high for the farmers, even with the higher priced end products. However, if the driers were installed in the villages it could be possible to increase their size and use, making them more economically viable.

Source: Final Technical Report: Solar Food Processing & Conservation (Phase II) submitted to WISIONS by ISES

# SOLAR REFRIGERATOR

Solar refrigeration technologies harness the energy of the sun and use it to run a cooling system. This type of solar application is an attractive option for the preservation of food and the refrigeration of vaccines and medicines in areas with a high intensity of solar radiation and no electricity supply (or only an unreliable supply).

The different types of solar cooling appliances that currently exist can be divided into two categories: the solar electric (solar PV) and the solar thermal refrigerators.

- Solar PV refrigerator

A solar electric refrigeration system consists mainly of a photovoltaic system that runs a conventional refrigeration device (i.e. a vapour compression cycle). The mechanical energy needed to run the cooling cycle, i.e. to compress the refrigerant, is provided by solar energy , as illustrated by Figure 7.

One of the main difficulties is ensuring a reliable supply of cold with only an intermittent supply of sunlight. The most conventional approach of dealing with this is the integration of a system for the storage of electric power, i.e. battery bank and charging controller.

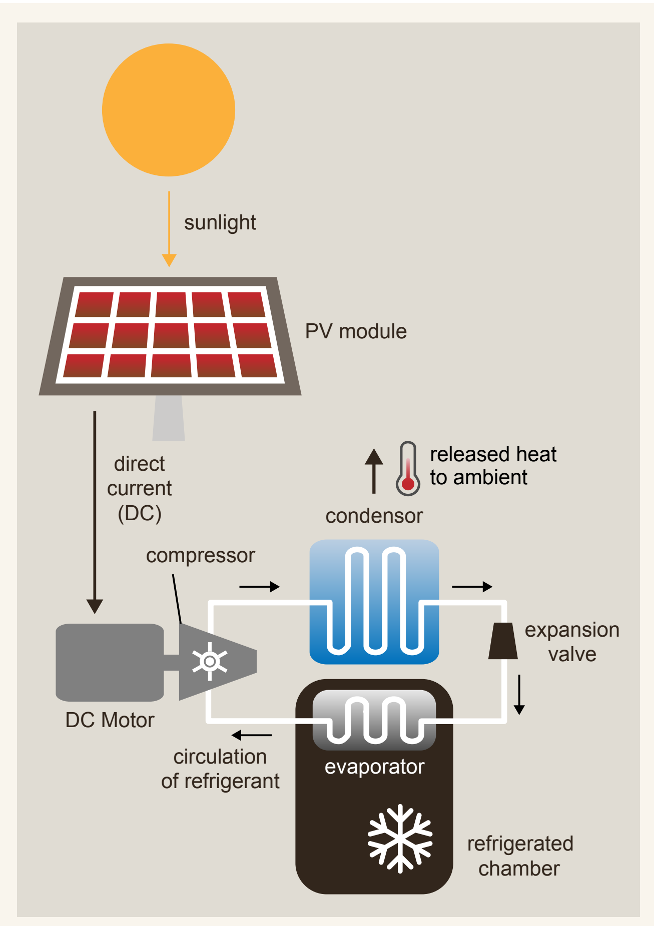



Figure 7. Schematic view of a conventional vapour compression cycle driven by Solar Photovoltaic

A promising alternative is to store the cold instead of the electric power. This so-called "Solarchill-technology" uses a direct current (DC) compressor to drive the refrigeration cycle. It produces and stores ice, which is then used as the main source of cool air to maintain a stable cool temperature [20].

- Solar thermal refrigerator

Solar thermal systems use solar heat to generate the cooling effect [21]. Among several methods that enable the use of heat to run a refrigerator, the absorption refrigeration cycle is the most commonly applied. During one cycle the refrigerant passes through four main stages (see Figure 8 for an schematic illustration):

1. In the evaporator, the fluid refrigerant evaporates by extracting heat from the product or room being refrigerated.
2. The evaporated refrigerant flows into the absorber where it mixes with the secondary fluid.
3. The resulting solution is then driven into the generator, where it is heated. This heat causes the refrigerant to vaporise.
4. The resulting vapour passes into the condenser, where it returns to liquid state and is ready to start a new cycle.

Another promising heat driven refrigeration option is the adsorption cycle. Within the adsorption cycle the refrigerant undergoes changes similar to those in the absorption cycle. However, instead of a liquid absorber, the adsorption cycle uses solid porous material (adsorbent), which is able to adsorb (take in) vaporised refrigerant when cooled and desorb (release) it when heated.

Absorption fridges running on kerosene or butane are already commercially available. Replacing combustion of fuels by concentrated solar heat is technically feasible. In new developments the sorbant (zeolite for instance) is integrated into a flat plate collector. More simple options in solar thermal cooling work with daily cycles: the sorbant is dried with solar heat during daytime and cold is only produced during the night. This can be seen as a disadvantage in comparison to the more sophisticated continuous cycles of the commercial ammonia based models.

## GLOBAL SUSTAINABLE ENERGY SUPPLY

Around 1.5 billion residential refrigerators and freezers are in use globally. The number of newly produced units has been increasing over the last decades and exceeded 100 million units per year in 2008 [22].

In future the global demand for cooling devices is predicted to increase even further, especially in developing countries and emerging economies. Off-grid solar refrigeration devices could become a suitable alternative for countries that benefit from high levels of stable solar radiation. However, currently, neither the solar electric nor the sorption refrigerator technologies can compete in terms of cost or efficiency with conventional domestic devices. The actual future potential of the technology will depend greatly on it being further developed and promoted.

## MILLENNIUM DEVELOPMENT GOALS

The preservation of food and the availability of fresh products thanks to cooling devices can help to improve food security and nutrition. Equally, the possibility of storing medicine and vaccines in remote areas can improve healthcare and help to fight diseases that are preventable by widely used vaccines. Therefore, solar refrigeration could, in principle, play a significant role in achieving the MDGs. However, the acquisition costs of such devices are, at present, too high for most households and, in particular, for the poor population in developing countries.

## DEVELOPMENT STATUS AND PROSPECTS

Solar photovoltaic refrigerators are already commercially available from different companies. It is estimated that over the past five years, at least 3000 photovoltaic medical refrigerators have been installed [19]. There are also some solar thermal refrigerators commercially available. However, to date, the market remains small and there is much potential for further development.

Innovative refrigerator concepts have been developed over the last decade targeting specific niche markets such as mobile homes and mini bars. Thermoelectric 'Peltier' refrigerators, cool boxes using zeolite and mini-refrigerators running on kerosene or butane are some notable examples. Although most of the designs are not driven by solar energy, there could be potential for specialised companies to further develop these types of concepts and adapt them to the particular situations of households and farmers in sunny regions.

Larger refrigerators for commercial and industrial use have also been developed, but these are mainly experimental prototypes rather than commercial products. Two current dynamics may trigger further innovation efforts in this field: the accelerated growth of urban centres, particularly in developing countries, and the subsequent demand for adequate food logistic structures (including large cooling facilities); and the very likely increase of energy prices that may follow the depletion of fossil resources and the pricing of carbon emissions..

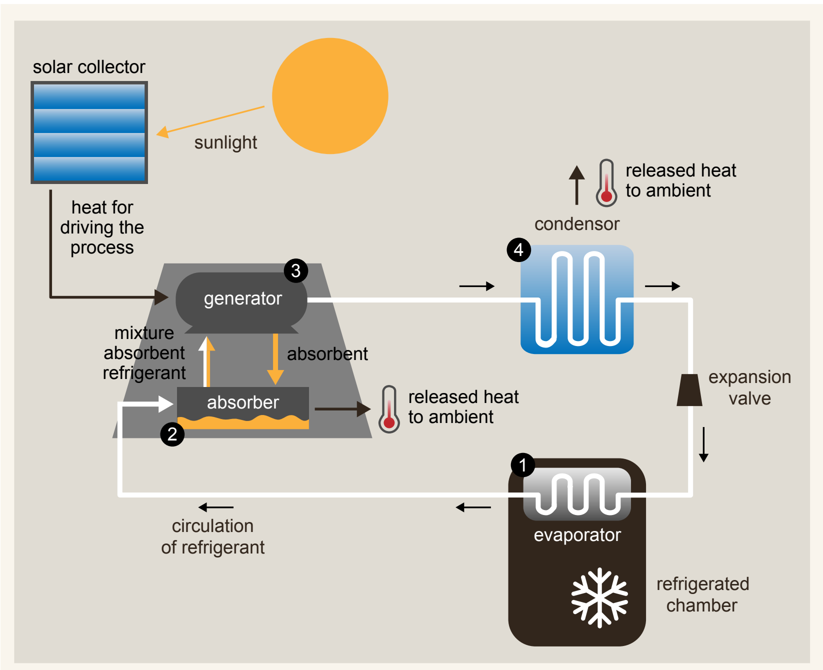



Figure 8. Schematic view of a absorption refrigerator driven by heat from solar radiation

# BIOGAS REFRIGERATOR

In principle, it is possible to use heat from biogas combustion to drive thermal refrigeration cycles, as illustrated by Figure 9. However, to date there appears to be a lack of refrigerators specifically designed to operate on biogas.

One way of using biogas for refrigeration is by adapting commercial absorption refrigerators that mainly run on kerosene or butane. Notably, the burner has to be modified or changed in order to deal with the particular character of biogas, such as its impurities and the varying levels of methane content.

The gas demand for refrigeration varies depending on the outside temperature, but on average for 100 litres refrigeration volume, about 2000 litres of biogas per day are required. A household refrigerator consumes about 3000 litres of biogas per day.

The use of biogas for powering refrigeration seems to be restricted to prototypes or individual examples where commercial absorption refrigerators have been adapted. Additionally, although the basic principles of heat driven refrigeration have long been known, this technology is little used in commercial applications. The development of technologies for generating cold from biogas (or for the simultaneous supply of power, cold and heat) appears to be an innovation field with significant potential. Harnessing this potential would require serious effort in terms of research, development and bringing the technology to market.

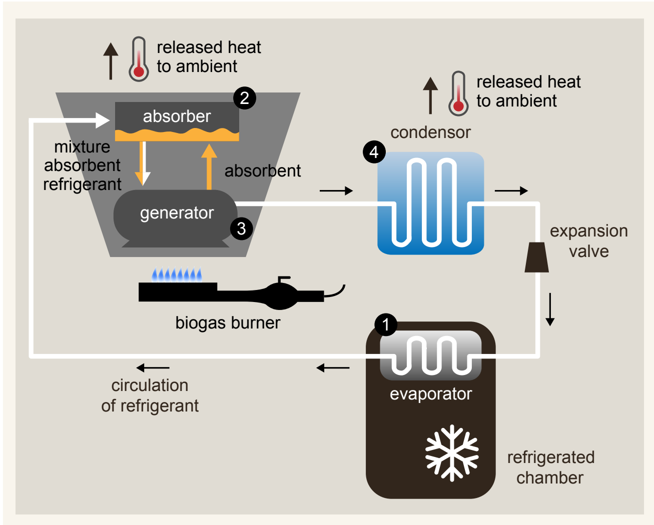


Figure 9. Schematic view of a absorption refrigerator driven by heat from biogas combustion

# EVAPORATION COOLING

Using the cooling effect of evaporation is a simple and low-cost cooling method that has been practiced by people for thousands of years. When it comes into contact with dry warm air, water evaporates and draws energy from the air, with the result that the air becomes humid and cools down. The efficiency and cooling effect depends on the humidity and temperature of the air. Evaporation cooling is not, therefore, applicable in humid tropical or cold regions, but is highly efficient in dry and hot climates [23].

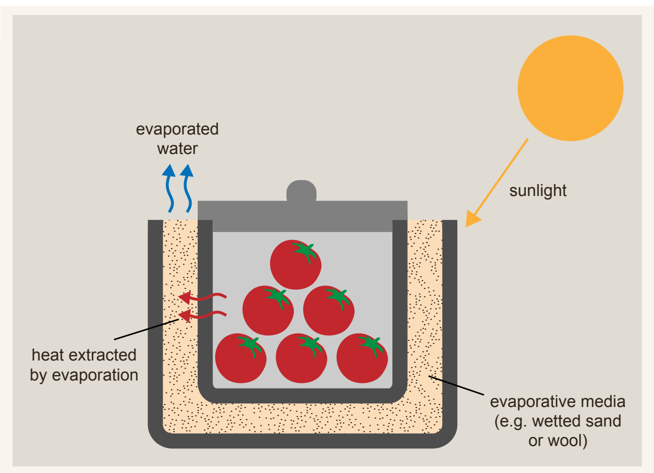


Figure 10. Schematic view of evaporation cooling

The evaporation cooling effect can reduce the temperature to between 10 and 25°C. These temperatures are sufficient for the short-term preservation of fruit, vegetables and other food [24]. The basic design consists of a smaller storage pot or structure that contains the fresh fruit and vegetables, which is placed inside a bigger pot or structure that holds an evaporative material like wetted sand or wool, as illustrated by Figure 10.

Evaporation coolers are not suitable for cooling large quantities of food for long periods of time, but can increase a product's durability five or tenfold. For example, tomatoes with a normal shelf life of 2 days could be stored for three weeks in this way [25].

For the preservation of fruit and vegetables the use of simple evaporation coolers is an affordable alternative to high cost cooling, especially for low-income households in dry and warm climates.

# MILLS AND OIL PRESSES

Rural families in developing countries spend substantial time and resource transporting crops to neighbouring mills or, if no milling facilities are available, milling daily by hand to prepare food.

Edible oils have a high nutritional value. Additionally, vegetable oil is very often a high value trading commodity at local markets. The ability to extract oil from crops can, therefore, improve both nutrition and the financial security of farmers.

Water and wind power have been used since ancient times for driving mechanical food processing, such as milling, grinding or oil extraction. In modern times, diesel engines and electrical power have replaced most of the traditional methods.

However, by combining advanced techniques and materials with the basic principles of those traditional concepts, some interesting developments are possible.

That is the case in improved versions of watermills. The watermill is an ancient technology that is still found manly in the Himalayas, India, Pakistan, China and even parts of Turkey. In particular, the use of advanced water turbines can translate into efficiencies of around 90% in the conversion of water flow into rotational energy.

Driving modern (conventional) milling and pressing equipment by renewable energy also appears to offer significant innovation potential. Notable examples are:

The integration of renewable electric power generation technologies (such as solar PV or small wind turbines) into milling or pressing equipment.

The use of plant oil or biogas to run conventional devices that traditionally use fossil fuels.

Practical examples of the afore-mentioned technological options are rather scarce and are restricted to a small number of enthusiastic people and organisations. The development of mature technologies that can gain broader diffusion will require greater efforts in terms of research and demonstration projects to test technical reliability and analyse the economic and social issues.

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