



# **OASYS SOUTH ASIA Research Project**

## **Working Paper Series**

### **Working Paper 03**

#### **Technical options for off-grid electricity supply**

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01 August 2012

Version: Final



## Abstract

This paper briefly discusses the characteristics and requirements of technologies for decentralized power generation with special reference to South Asian countries. The individual technologies are then discussed in terms of resource characteristics, technology description, economic analysis, advantages and constraints, and current status. The discussions benefit from the personal experience of one of the authors in technology development as well as extensive field visits and stake-holder interactions in India. It is observed that none of currently available technologies is individually capable of addressing the problem of energy poverty in the developing countries. It is only with further advances in technology and with the deployment of the full range of renewable energy technologies that universal energy access is achievable. Though the observations and conclusions are based on experiences in India, these seem to be relevant to all developing regions which have no access to modern energy services.

Key words: off-grid technologies, small hydro, solar PV, wind, biomass gasification, bio-methanation.

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## 1.0 Introduction

The importance of decentralized options, either as short term solutions or as future plug-ins for energy grids, becomes evident from the fact that 1.3 billion people lived without adequate access to electricity services in the world in 2009 and that there is now growing acknowledgement of the fact that achieving 100% electrification even by 2030 seems ambitious particularly for Sub-Saharan Africa (Bazilian et al., 2012). It is increasingly becoming important that such off-grid or decentralized solutions be tried out until the local economy reaches a certain level where productive activities dominate in comparison with minimal sustenance activities, so that users of the modern energy services can pay for these, leading to sustainable development. A number of technologies exist with different characteristics and degree of maturity. As any discussion about the off-grid electrification options is centred around specific technology choices, the purpose of this paper is to provide a basic overview. It provides a review of different technologies which can be employed for decentralized power generation using local resources. The review includes technology descriptions, limitations, economic considerations and research needs.

## 2 Basics of decentralized electricity generation

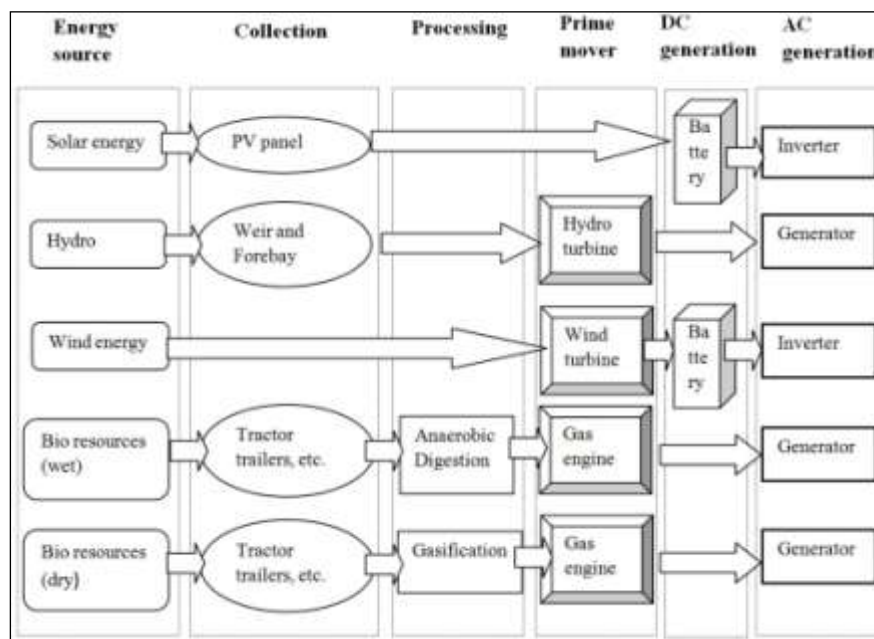
The basic difference between centralized and decentralized power generation is related to scale. While centralized technologies can strive to achieve energy conversion efficiencies to the extent allowed by thermodynamics at reasonable costs, the same cannot be said about decentralized technologies. The other important distinction is that, owing to the somewhat skewed power demand (essentially the lighting load during 3-4 hrs after sunset and occasional demand for electric motors), the base load tends to be zero (or very low) for decentralized generation until the local economy develops to some level. This means that the plant load factor (PLF) or utilization factor for decentralized systems is necessarily quite low to start with, thereby further reducing the financial viability of the system.

Power generation technologies can be broadly classified into two categories: one producing Direct Current (DC) and the other producing Alternating Current (AC). Photo-electric devices, thermo-electric devices and fuel cells fall under the first category. The DC can either be used directly or converted to AC using inverters. The latter is the preferred option as most appliances available in the market are AC driven. The second category comprises the prime mover-generator system. Well known prime movers are steam turbines, gas turbines, water turbines, wind turbines and a variety of reciprocation engines fuelled by diesel, petrol, gas etc. It should be noted that, though a variety of prime movers are available, some are either expensive or difficult to manage in a decentralized mode. For example, although small-scale steam generators can be built, those would need small sized

boilers and de-mineralized water, which would either add to the costs or would require skilled manpower which would be difficult to obtain in rural areas. Also, some heat source-prime mover combinations are better than the other. The geothermal-Organic Rankine Engine combination would be more feasible than the Solar Pond- Organic Rankine Engine because the solar pond would require higher maintenance than a geothermal source. The generators can be classified as induction, synchronous and permanent magnet generators. However, for induction generators, an active grid is needed; hence it would not be an option for decentralized generation. The energy sources for the prime movers can be hydro (potential energy), wind (kinetic energy), heat from solar energy, geothermal sources etc. and a variety of fuels such as biodiesel, bio-methane and producer gas (chemical energy). The last category of fuels are usually obtained after some processing of primary fuels such as oil seeds, organic residues and a variety of biomass materials such as firewood and agro-residues. The conversion processes involved are: esterification, biomethanation and biomass gasification.

Some technologies, such as the Ocean Thermal Energy Conversion, geothermal energy, tidal power or wave energy conversion are not considered here because of a variety of reasons such as non-amenability for small scale, non-availability of mature technology or high site specificity.

The complex chain of processes involved in decentralized power generation is represented in Fig. 1. The individual technology options are described in the next section.



**Fig. 1** The chain of operations involved in decentralized power generation

### 3 Different technology options for decentralized generation

#### 3.1 Micro-hydro power

Hydro power is the power produced by harnessing energy from the flow or fall of water in rivers, streams or canals. Water pressure is converted using a hydro turbine into mechanical energy, which can then be used either to drive an electricity generator or for running small industrial applications that require shaft power, such as a grain mill. Hydropower systems that generate 5 - 100 kilowatts (kW) of electricity are often called micro hydro systems and systems even smaller are called pico-hydro systems. These systems are mostly “run-of-river”, which means that no dam or water storage is required for their operation. However, they do need water diversion and conveyance systems.

Micro-hydro power (MHP) is environmentally benign and could be a cost-effective solution for electrifying isolated communities located in mountainous regions where extension of the electricity grid is not feasible. It could also be used in the plains if adequate flowing water is available throughout the year.

##### *3.1.1 Micro hydro resources*

The best geographical areas for harnessing micro hydro power are those where there are perennial rivers and streams flowing through steep hills and mountains. In South Asia, the potential for micro hydro power exists in almost the entire Hindu-Kush Himalayan region, which includes Afghanistan, Pakistan, Nepal, Bhutan, Northern India and Myanmar. Huge potential also exists in several locations in Sri Lanka and Southern India due to their unique geo-climatic conditions.

The power potential of the water in a stream depends upon the flow rate (volume per unit time) of the water and the head (vertical drop) through which the water can fall. The theoretical power potential at a particular site can be estimated as:

$$P = Q \times H \times 9.81 \text{ (kW)} \quad (1)$$

Where,

P → theoretical power potential at a site

Q → flow rate in cubic metres per second

H → head in metres

9.81 → product of the density of water and the acceleration due to gravity (g)

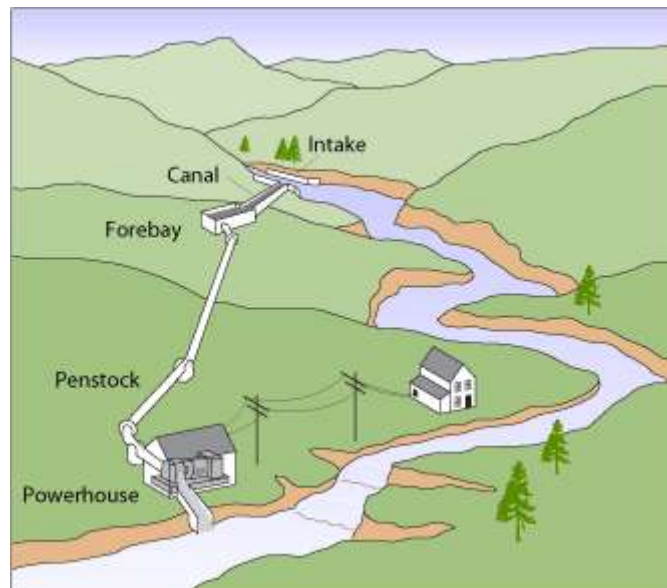
However, energy is lost while getting converted from one form to another due to inefficiencies and losses in various components of the power generation system. In practice, the efficiency of most MHP systems ranges from 30 - 70%. Therefore, a more realistic power potential can be estimated by multiplying the theoretical power by 0.53 (NREL 2001).

### 3.1.2 Micro hydro technology

A MHP system typically includes

- Water conveyance system—these are civil structures such as a weir and an intake to divert water from the stream and a channel, a tank (fore bay) and a pipe (penstock) to conduct water to the turbine
- Turbine—transforms the energy of flowing water into rotational shaft power
- Drive system— transmits the shaft power from the turbine to the generator or other mechanical appliances
- Electrical system— convert mechanical power into electrical power. It consists of a generator, an alternator and an electronic controller.

The general schematic of a run-of-the-river hydropower system is shown in Fig. 2.



**Fig. 2** Schematic of a typical run-of-the-river micro hydropower system (Source: DOE/NREL)

This figure is reprinted from "Small Hydropower Systems: Energy Efficiency and Renewable Energy Clearinghouse (EREC) Fact Sheet," DOE/GO-102000-1173 (2001), Accessed July, 2012

The core of any MHP system is the turbine. Based on the head pressure, turbines are generally classified as high-head, medium-head and or low-head. No formal classification for head pressure exists; the classification is only relative to the size of the turbine. The turbines are also classified based on their principle of operation as (see Table 1):

- Impulse turbines—these convert the kinetic energy of jets of water striking the turbine buckets/ blades running freely in air. No pressure reduction occurs in these turbines.
- Reaction turbines—the rotating part (runner) of these turbines is completely submerged in water and is enclosed in a pressure casing. The linear and angular momentum of water flowing through the turbine is converted into shaft power. They are suitable for medium and low heads.

The choice of turbine for any particular hydro site depends primarily on the net head and flow available. The selection also depends on the desired running speed of the generator or other connected mechanical appliances and whether the turbine will be expected to produce power under reduced flow conditions. More than one turbine could also be chosen at times to match the variations in flow during the peak and lean seasons.

**Table 1** Classification of turbine types

Turbine type	Head pressure		
	High	Medium	Low
Impulse	Pelton	Cross-flow	Cross-flow
	Turgo	Turgo	
	Multi-jet pelton	Multi-jet pelton	
Reaction		Francis (spiral case)	Francis (open flume)
		Pump-as-turbine	Propeller
			Kaplan

Source Harvey et al. (1993) and Paish (2002)

### 3.1.3 Economics

MHP plants are more expensive and are often less competitive as compared to larger sized hydro power plants. The cost is highly site specific and depends on the site characteristics such as the terrain and accessibility, in addition to various other factors such as the availability of labour for civil works, availability of local manufacturing of electro-mechanical equipment, the sizing of the plant and the distance of load from the power house. Costs can be controlled to an extent by proper sizing, by utilizing local materials and indigenous technology and by adopting appropriate standards. The investment per kW of electricity ranges from \$1136 to \$5630 per kW, with an average of about \$3085 (Khennas and Banett, 2000). However, the investment required for mechanical power alone would be significantly lower at around \$714 to \$1233 per kW (Khennas and Banett, 2000) due to the absence of expensive electrical/electronic equipment and the distribution lines.

The operational costs on the other hand are highly competitive and are usually lower than many other sources of energy. Most MHP plants could operate for up to 50 years without requiring any major refurbishment (Paish, 2002). This brings down the cost of energy drastically if the economics are worked out for the entire life of the project. The levelized cost of energy for a typical MHP plant ranges from \$0.1 to \$0.2 per kWh (ESMAP

2007). The energy cost reduces further if the generated power could be fed into the main electricity grid.

### ***3.1.4 Benefits***

Unlike large hydro plants, the adverse impacts on the environment are minimal for MHP. The energy source is predictable and power is available continuously on demand. An MHP installation usually lasts for several decades. The operational cost of the plant is very low. The operation is simple as well and training requirements are minimal. Further, most components of an MHP plant can be manufactured or assembled locally. The turbine's shaft power can also directly drive machinery such as a mill at a higher efficiency, thus making a cost-effective option for several energy services.

### ***3.1.5 Limitations and barriers***

MHP is a highly site specific technology and therefore requires an extensive assessment of resource and site characteristics before installation. Modifications to the river or stream might require approvals from multiple government agencies. Also hydro turbines may not be readily available in smaller sizes. All these factors could increase the project development time up to 1 year.

The limited availability of the resource at the site prevents up-scaling of the plant in the future. River flows are more seasonal in nature than solar or wind resources. Hence the plant utilization could drastically fall during the months of lesser water flow. Possibility of conflicts with other downstream uses of the water source such as fisheries is another crucial parameter that needs to be considered while planning the project.

Due to its high initial investment requirement, MHP may not be affordable by remote, isolated communities without heavy subsidies. The cost for energy distribution can occasionally be very high if the load is located far from the point of power generation. In such cases, the project implementation would be highly dependent on government or external aid. Unavailability of spares and service locally is another critical factor that could affect the viability of the project.

### ***3.1.6 Status of the technology***

The history of MHP in South Asia can be traced back to the traditional ghatta or water mills used in Nepal for grinding flour. Thousands of such water mills existed in Nepal for many centuries and even today, many installations of the improvised ghatta —Multi-Purpose Power Unit (MPPU) are being used in this mountainous country. The modern MHP technology, on the other hand, was derived from the larger hydro technology and is only about four decades old in South Asia. The technology has evolved considerably over the



past few decades, with several manufacturers and project developers currently available in the region.

MHP is currently among the most mature of small-scale technologies for decentralized electrification. However, the technology has not been massively disseminated in spite of its vast potential in almost all the countries in the region. The reasons for this are the lack of local manufacturing, the higher initial cost per kilo Watt, lack of specific government policies and the disproportionate attention given to larger sized hydro installations. Most of the existing off-grid MHP installations in South Asia are driven either by donor funds or by passionate technocrats. With increasing awareness of the technology, the situation can be expected to improve in the future. Current efforts in MHP technology for off-grid electrification are focused on cost reduction, increase in reliability of the system, local manufacturing and servicing of critical components, newer technical designs for low flow and low head and regional cooperation for manufacturing and development of standards.

### *3.2 Biomass gasification*

The term 'biomass' refers to a wide range of non-fossil organic matters derived from the products of photosynthesis occurring in plants and algae. Solar energy captured during photosynthesis is stored in biomass, thereby making it a high-energy density source. Biomass resources are highly versatile and can be used in a solid, liquid or a gaseous form for producing electrical power, heat, bio-fuels and other useful by-products. Biomass has been a major energy source to mankind, prior to the discovery of fossil fuels such as coal and petroleum. Even today, about 30% (IEA 2011) of the total primary energy supply in South Asia is derived from biomass, used predominantly for cooking and heating. With recent advancements in technology and an increasing awareness of its potential benefits, there has been a renewed interest in biomass as a source of power generation. Power generated from biomass is considered to be renewable if the consumption of biomass matches to its production.

Several processes exist to convert biomass into fuels that can run engines to produce electricity. These conversion processes are broadly classified as:

- Thermo-chemical processes (combustion, gasification, pyrolysis, liquefaction)
- Chemical processes (esterification)
- Biochemical processes (acid hydrolysis, enzyme hydrolysis, fermentation)

Among these, the most widely used technologies for decentralized power generation are combustion and gasification of solid biomass, and anaerobic digestion of organic matter for production of biogas, which is then combusted for power production. Among the thermo-chemical processes, power generation through gasification is the simpler and more

economical option for low capacities of 10 - 500 kW, which are typical for off-grid installations.

### ***3.2.1 Biomass resource availability for gasification***

Biomass resources are highly versatile and are abundantly available in all the South Asian countries, especially in the rural areas. The biomass resources suitable for gasification can be derived from forests and wastelands and from residues of agriculture and related processing industries. Based on their bulk density, biomass resources are broadly classified as woody and non-woody (or powdery). An indicative list of the different types of biomass resources is given in table 2.

**Table 2** Examples of biomass suitable for gasification

Forest residue	Agricultural residue	Agro-processing residue
Forest pruning	Paddy straw	Rice husk
Wood from energy plantation	Wheat straw	Cashew nut shells
Wood from marginal lands	Maize stalks	Oilseed shells
Grasses and bushes from wastelands	Cotton stalks	Oil cakes
Wood pulp	Maize cobs	Coconut shells and fibre
Saw dust	Mustard stalks	Coffee and tea waste
Bamboo waste	Millet straw	Bagasse

Despite being widely available, very little documentation is available regarding the availability and variability of biomass resources due to their scattered nature. Existing assessments of biomass resources in most developing countries are only macro-level estimates that use an inventory approach. These assessments are based on simple calculations that factor in the available forest, agricultural and waste lands, the cropping patterns in the country/region and the alternative uses of biomass. Examples of calculations for biomass resource estimation from ground inventory are given below (Kishore 2008).

From woody biomass:

$$\text{Annual sustainable yield (ASY)} = 2 * \text{growing stock} / \text{rotation} \quad (2)$$

$$\text{Extractable sustainable yield (ESY)} = \text{ASY} * \text{collection efficiency factor} \quad (3)$$

$$\text{Surplus woody biomass available for energy production} = \text{ESY} - \text{alternative uses of biomass} \quad (4)$$

From agricultural residue:

$$\text{Residue production} = \text{grain production} * \text{residue-product ratio} \quad (5)$$

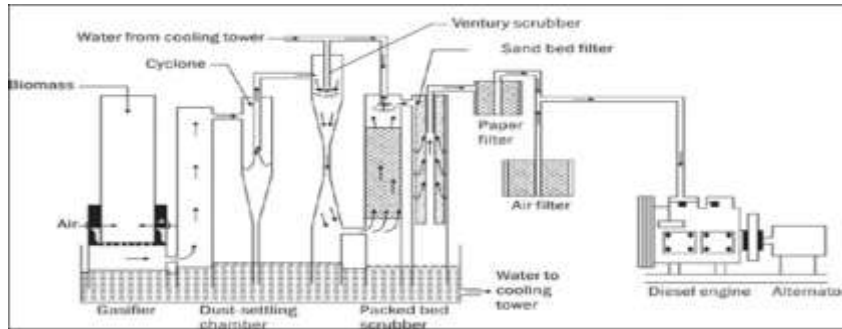
$$\text{Surplus agricultural residue available for energy production} = \text{residue production} * \text{collection efficiency factor} - \text{alternative uses of biomass} \quad (6)$$

These assessments usually have an error of 15 – 20% (Pathak and Srivastava 2005) and can at best be used as preliminary inputs for project design. More advanced resource assessment techniques involve utilization of geospatial technologies, simulation modelling and field surveys. These methods are usually more labour-intensive and require immense resources but tend to be more accurate. The ‘National Biomass Resource Atlas’ of India prepared by the Indian Institute of Science by integrating GIS data from the Indian Space Research Organisation, statistical data from the Ministry of Agriculture and residue data from other sources has been the biggest biomass resource assessment exercise till date in South Asia.

### ***3.2.2 Overview of Biomass Gasification technology***

Gasification is a thermo-chemical process that converts solid biomass into a flammable gas mixture at high temperatures. The resultant gas called ‘producer gas’ or ‘syngas’ contains carbon monoxide (CO), hydrogen (H<sub>2</sub>), methane (CH<sub>4</sub>), nitrogen (N<sub>2</sub>), carbon dioxide (CO<sub>2</sub>) and smaller quantities of higher hydrocarbons. The gasification process occurs through a sequence of complex reactions: (i) Drying of biomass, (ii) Pyrolysis —heating in absence of air to release volatile matter, (iii) Partial combustion — produces Carbon dioxide, water vapour and char (iv) Reduction — reduction of the gases by char into Carbon monoxide and Hydrogen.

Gasifiers are generally classified depending on the way the fuel is brought in contact with air (or oxygen). Gasifier designs are broadly classified into: Fixed bed and Fluidised bed gasifiers. A further distinction can be made based on the direction of air flow as: updraft, downdraft and cross-draft. Based on the gasifier design, the producer gas contains varying portions of contaminants such as condensates (tar) and particulate matter. Tar cannot be tolerated in the engines, and hence, the gas has to be cleaned using devices such as gravity filters, wet scrubbers, cyclone separators and bag house filters before being fed to the engine. A general schematic of a typical biomass-gasifier based power system is given in Fig. 3.



**Fig. 3** Schematic of a gasifier system for power generation (Source: [www.teriin.org](http://www.teriin.org))

The important parts of a gasifier based power generation system are:

- **The reactor** –thermo-chemical reactions occur within the reactor, resulting in producer gas
- **The cooling and cleaning system** – this consists of a cyclone to remove the dust, scrubbers using water as the medium for cooling and filters for cleaning the gas from impurities such as particulate matter and condensates (tar)
- **The engine** – this could be a dual-fuel compression ignition, or a spark ignition or a 100% producer gas engine that runs on the clean gas and provides mechanical power to the generator
- **Essential Auxiliaries** – these include systems for biomass conveyance, biomass preparation, fuel handling, driers and water treatment (if re-circulated)

### 3.2.3 Economics

The capital cost of biomass gasifier based power generation systems varies widely based on numerous factors such the size of the system, the material used for the reactor (stainless steel or mild steel), the choice of engine (CI or SI or Producer gas engines), the types of sensors and controls used and the type of cooling and cleaning mechanisms. An increase in the scale of operation reduces the price per kW significantly; whereas choosing modern equipment such as 100% producer gas engines or SCADA control systems increases the initial cost drastically (see table 3).

The cost of electricity generated too varies widely from about \$0.08 to \$0.14 per kWh depending on several factors such as the cost of feedstock, labour costs, capacity utilization factor of the plant and the distance over which the feedstock needs to be transported.

**Table 3** Typical capital costs of biomass gasifier based power plants

Size of the plant	Capital cost (\$/kW) (Excluding land cost)
10 – 35 kWe with dual-fuel engines and minimal control systems	850 – 1750
50 – 100 kWe with 100% producer gas engines and minimal control	1500 – 2880

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Systems

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250 kWe – 2 MW with 100% producer gas engines, water treatment system and SCADA controls 1200 – 2030

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**Source** ESMAP 2007, Gol 2009 and field visits conducted in India; Assumption of 1\$ = INR 45

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### ***3.2.4 Benefits***

Unlike solar and wind energy technologies which are dependent on intermittent sources, biomass gasification is capable of providing firm power and can therefore be operated at high utilization rates to meet both the base load and the peak load. A huge untapped potential exists in South Asia for utilizing the biomass resources which until now are going waste. The technology could easily be retrofitted with existing diesel based generation facilities, thereby leading to a gradual fossil fuel replacement. An immense scope also exists for further efficiency improvements in the current technology by employing waste heat recovery, by operating in combined heat and power (CHP) mode or by employing gas turbines. Adopting biomass gasification can lead to several social, environmental and economic co-benefits as well. Almost 70 - 80% of the cost of power generation will go back to the rural community in terms of cost of biomass feedstock and for employing local manpower, thereby resulting in increased prosperity. Large scale plants, when planned with dedicated energy plantations on waste lands to supply fuel lead to afforestation in the region. Potential for recovering value-added products such as activated charcoal and precipitated silica (rice-husk gasifier) from the char obtained in the reactor could make the technology more economically attractive in the future.

### ***3.2.5 Limitations and barriers***

The quality of producer gas is highly dependent on the feedstock type, its moisture content and its sizing. Hence utmost consistency had to be maintained in the feedstock supply. Ensuring the sustainability of the biomass source throughout the lifetime of the plant could at times be a huge challenge. Monetization of fuel- wood, crop and agro-processing residues could adversely affect their present uses and could possibly lead to a competition for scarce land and water resources. Further, the operational expenditure of the plant is highly dependent on the cost of feedstock, with very little scope to hedge against any future price hike. Thus the viability and scalability of the plant is limited by the availability of feedstock in the region. The scalability could be severely restricted if the plant is dependent solely on energy plantations.

Biomass preparation by cutting of woody biomass and by briquetting or pelletization of powdery biomass requires significant electrical power. In addition, water is required for scrubbing the producer gas. Hence a water treatment plant could be essential for large sized

plants to meet the local pollution standards. The operation and maintenance of the plant is labour-intensive and requires extensive training. Unavailability of skilled operators in rural areas could severely affect the operation of the plant.

### ***3.2.6 Current status of the technology***

The development of biomass gasification has always been in spurts since the 1850s, with the maximum intensity observed during the World War II and during the energy crisis of 1970s. The technology received a boost again in the 1980s and several demonstration projects were set up in Europe, US and a few developing countries such as Brazil, India and Indonesia based on indigenous models. Most of these were unsuccessful due to technical, economic and institutional problems (Pathak and Srivastava 2005). A notable effort in South Asia during the 1980s was the setting up five Gasifier Action Research Centres in India. The R & D programmes were carried out in these centres resulted in the fabrication of new prototypes, development of testing standards, development of gas cleaning systems and the application of gasifiers in other sectors such as agricultural processing, steel rolling, ceramic kilns and cold storages (Pathak and Srivastava 2005). A 250kW 100% producer gas engine was also developed during this period.

Decentralized power generation through biomass gasification has been proven to be commercially viable in many countries today. However several technical and operational issues still remain to be overcome to advance the maturity of the technology. Most small-scale gasifiers are still based on the conventional open-top, down-draft configuration. Attempts are being made for newer configurations that produce lower tar, such as two-stage gasification, dual-air entry configurations and twin fire configurations. In addition, research is ongoing to eradicate slagging/corrosion problems in the reactor, to identify more reliable materials for reactor construction, to reduce the contaminants in the gas, to enhance the fuel flexibility and to develop effective process controls for the plant operation.

## **3.3 Biomethanation**

Biomethanation refers to the production of a combustible gas by the anaerobic fermentation of biomass (substrate) in a humid atmosphere and in the presence of different species of naturally occurring bacteria. Biomethanation is a complex biochemical process occurring in three sequential stages — enzymatic hydrolysis, acid formation and methane formation, with different types of bacteria acting on the substrate at each stage. The resultant 'biogas' composes of methane (50 – 70%), carbon dioxide (30 – 40%), hydrogen (5 – 10%), nitrogen (1 – 2%), water vapor (0.3%) and traces of hydrogen sulphide (Karki et al. 2005). With an average calorific value of 21-23.5 MJ/m<sup>3</sup> (Dimpl 2010), biogas can be combusted in engines to generate power and is hence considered as a promising renewable source of energy.

### 3.3.1 Biomass resources for Biomethanation

Any biomass that contains carbohydrates, proteins, fats, cellulose and hemicellulose as its main components is theoretically suitable for biomethanation. Examples of biomass (substrate) suitable for anaerobic digestion include (i) Animal waste — manure from cattle and pigs, chicken litter, human excreta, slaughter house waste (ii) Market waste — vegetable waste, spoilt grain and cereals (iii) Wastes from households and canteens — leftovers, eggs, bread (iv) Agricultural residues — straw, stalks, leaves, roots, sugarcane trash (v) Food processing waste — mash from fermentation, molasses, spent fruits (vi) Weeds and algae. Cattle dung has by far been the most widely used feedstock for biomethanation by the rural communities in South Asian countries.

The nature of the substrate determines the type of bacteria acting on it and also the composition of the generated biogas. Maintenance of optimum microbial activity is crucial to gas generation which is in turn is dependent on a variety of parameters. Few of the critical parameters are mentioned in the table 4.

**Table 4** Critical parameters for biogas production

Parameter	Description	Optimum value
Digestion temperature	Temperature affects the enzymatic activity of bacteria and influences the rate of biogas production. Gas production reduces with temperatures below 25°C and virtually stops below 10°C	30 - 40°C (mesophilic) 45 - 55°C (thermophilic)
pH	pH is the measure of substrate's acidity or alkalinity	6.8 to 8.0
Retention time	It is the average time the substrate remains inside the digester. It can be varied to maximize the yield based on the type of substrate, the digester design and temperature	40 – 100 days
Carbon-nitrogen (C:N) ratio	For optimal growth of bacteria, it is essential that nutrients are available in the correct concentration	25-30 :1
Loading rate	It is the amount of substrate fed into the biogas digester per day per unit volume of digester. Overfeeding results in acidity and	6kg of dung per m <sup>3</sup> of

	underfeeding reduces the gas production	digester capacity
Dilution	Optimum gas production occurs when the 1:1 for substrate is diluted with water such that the input slurry has a total solid concentration of 8 – 11% by weight <sup>fresh dung</sup>	
Co-substrate	The plant materials such as straw and sawdust contain a higher C:N ratio while animal wastes such as chicken litter and human excreta have a lower C:N ratio. Use of a co-substrate helps in judicious manipulation of C:N ratio to maximize the biogas yield	
Toxicity	Presence of toxic materials such as heavy metals, ammonia, volatile organic acids, detergents and mineral ions in the substrate inhibits the growth of bacteria. Ammonia toxicity is often encountered in substrates with high protein content	

The gas production can be enhanced by (i) Mechanical methods such as stirring the digester and recycling a fraction of the slurry; (ii) Thermal methods such as insulating the digester, pre-heating the input slurry, solar heating the digester and composting around the digester; (iii) Bio-chemical methods such as addition of urine, urea, molasses and sugar wastes (Nijaguna 2009).

### 3.3.2 Biomethanation technology for power generation

The principal components of biogas-to-power plant are:

**Digester:** The physical structure where methane is produced by anaerobic digestion of biomass is known as the bioreactor/digester. The digester could be of vertical or horizontal design; cylindrical, spherical or hemi-spherical shape; and could be constructed above the ground, partially underground or completely underground. Although several types of biogas digester designs can be found in different parts of the world, the models that are widely used in the context of South Asia are (see Fig. 4):

- (i) The KVIC model: This is a floating drum digester that was first developed in India in 1956. It was later adopted by the Khadi Village Industries Commission of India and came to be known as the KVIC model. It consists of a deep well made of brick masonry in cement mortar acting as the digester and a gas holder made of mild steel in the shape of an



inverted drum. The drum 'floats' atop the digester corresponding to the accumulation and withdrawal of gas, guided by a central coaxial pipe,

- (ii) The GGC model: This is based on the fixed dome Chinese model and was designed by the Gobar Gas and Agricultural Equipment Development Company (GGC) of Nepal in 1980. This model consists of a brick masonry digester with a concrete dome on the top for gas storage. The digester and dome together form a single underground unit.
- (iii) Deenbandhu model: It is also based on the fixed dome Chinese model and was designed by the Action for Food Production (AFPRO), New Delhi in 1984. This was meant to be a cheaper version of the Chinese model with the dome structure being constructed of brick masonry instead of concrete.

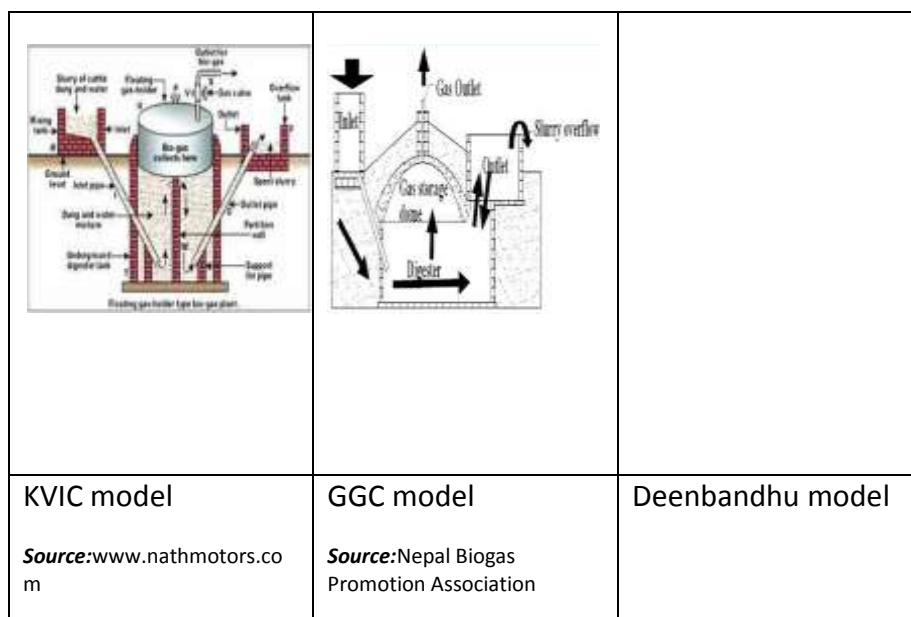
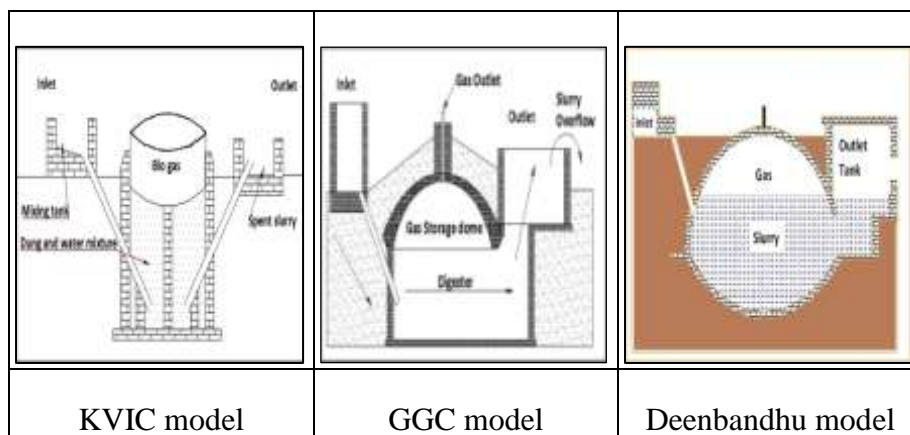


Fig. 4 Models of biogas digesters

Several other digester designs have been experimented or are being piloted in South Asia which is more suited to the local conditions. For instance, in the hilly regions of Nepal where transportation of construction material could be expensive, bag digesters are currently being piloted. Selection of the type of digester is based on several factors such as the cost of raw materials for construction/fabrication, the climatic conditions, availability of water and the availability of skilled man power for the construction, installation and operation of the plant.

**Gas storage:** Not all the biogas produced may be consumed immediately. Moreover, the point of consumption might be far from the digester. This necessitates the storage of gas in low-pressure biogas holders and bags made of double-membrane or thermoplastic foil or medium-pressure holders made of steel.

**Residue tank:** Spent slurry from the digester is stored in open tanks for drying before being used as a bio-fertilizer. Storage in a series of small tanks used in rotation not only makes the removal of dried residue easier but also increases the overall cleanliness of the plant.

**Gas cleaning systems:** Biogas contains several impurities such as dust, water vapor and traces of sulphur dioxide. Water vapor and carbon dioxide in the biogas reduces its calorific value; hydrogen sulphide and its combustion product SO<sub>2</sub> can cause severe corrosion in pipes and metal parts of the engine. The solid particles in biogas are filtered with dust collectors. Water vapor is removed by condensation either in the gas storage or by dehumidification on its way to the engine. Hydrogen sulphide and other trace gases are removed by scrubbing, adsorption, absorption or other chemical and biological processes.

**Engine:** In theory, biogas can be used as a fuel in almost all types of combustion engines such as diesel engines, gas engines, gas turbines and Stirling engines. However in practice, only modified diesel engines in dual-fuel mode are widely used in South Asia, owing to their lower capital costs and easier availability in smaller sizes. Gas engines that run on biogas are slowly gaining popularity due to their lower fuel costs. Running the engines in combined heat-and-power (CHP) mode increases their overall efficiency. Heat recovery can also be used for heating the digester during colder months of the year.

### ***3.3.3 Economics***

The capital cost, operating and maintenance costs of a biogas power generation system vary widely based on the scale of the system, the type of civil construction and the choice of engine. The typical cost a biogas power plant is estimated at around \$1890 (MNRE 2008) to \$2490 per kWe (ESMAP 2007). The cost for different types of engines varies between \$1200 to \$1600 per kWe (Deublein and Steinhauser 2008). With civil construction and labour constituting roughly 30-40% of the capital cost, the availability of construction materials and labour costs in the region also play a substantial role in arriving at the total capital cost.

The cost of power is primarily dependent on whether the biomass had any previous use and the monetary value attached to it. Though several theoretical studies have estimated the levelled cost of energy from biogas at around \$0.07/kWh, a more realistic figure calculated by GTZ experts in Kenya puts this at about \$0.15/kWh (Dimpl, 2010).

### ***3.3.4 Benefits***

Biogas digesters are simple in construction and could be adapted according to the needs, climatic conditions and building materials in many countries or regions. The produced biogas can be stored in bags, balloons or cylinders and could be transported to remote places such as agricultural fields for running engines. Existing engines can be modified to run in dual-fuel mode with minimal modifications, thereby contributing to gradual replacement of fossil fuels for power generation. The operation and maintenance of a biogas plant is technically simple and training requirements are minimal. Operational costs too are minimal since the cost of feedstock is usually low and at times almost zero.

Use of biomethanation for disposal of organic waste is relatively cheaper as compared to land filling or combustion of waste. It can therefore be an effective technology for sewage treatment in rural areas of under-developed countries where facilities for sewage disposal do not usually exist. Biomethanation of waste reduces the pathogen content in the substrate materials and thereby helps to improve the health of the community. The profitability of the plant could be enhanced substantially with the sale of slurry as a bio fertilizer and the sale of excess biogas for cooking and heating applications. Use of spent slurry as a natural fertilizer not only increases soil fertility but also reduces the dependence on the supply of chemical fertilizers.

### ***3.3.5 Limitations and barriers***

The biggest barrier for the diffusion of biogas technology is to overcome the negative perception about the technology in countries where many previous installations have failed. Daily procurement of sufficient biomass is a critical requirement for a biogas plant's sustained operation. This means that plants utilizing animal manure can be located only in such places where sufficient livestock is stabled at a single location. This could restrict the technology to only a few richer communities with larger livestock population and to communities with excellent synergy for resource sharing. Also, the dependence on feedstock such as cattle dung or poultry litter for power generation could affect their present uses. Such competing uses of feedstock could have an adverse impact on the plant's operation.

Preparation of input slurry for the plant requires substantial amounts of water. Water recycling would hence be required in locations with scarce water resources. The digester requires an extensive overhaul once every few years to prevent reduction in gas output

due to scum or silt. Low temperatures at higher altitudes and during winters can also severely reduce the production of biogas.

### ***3.3.6 Current status of the technology***

The utilization of biogas as a source of energy in South Asia could be traced back to as early as 1859 when biogas generated by the purification of waste water from a leprosy hospital in Bombay was used for emergency lighting. However, biogas was recognized as a promising source of energy for cooking only a century later. Several digester designs based on the fixed dome and the floating drum designs were experimented in South Asia since the 1950s. The governments in Nepal, Pakistan, India, Bangladesh and Sri Lanka launched several subsidy based programmes to promote biogas for cooking in rural areas. Several millions of biogas digesters were installed in these countries. However, very few of them are fully functional today. Their failure could be attributed to several reasons such as lack of technical training, high costs of maintenance, lack of sufficient feedstock and inadequate community participation. With most of the technical issues rectified during the past few decades, biomethanation stands today as a mature technology capable of uninterrupted operation. Currently, several large scale plants that generate power from biogas derived from cattle manure, chicken litter, vegetable waste and municipal solid waste exist in South Asian countries. However, generation of electrical power at a smaller scale in off-grid locations is still relatively new in these countries. The few biogas-to-power plants that have been installed in off-grid regions during the past few years were driven primarily by the support of international agencies and by private enterprises seeking an alternative source of reliable electric power.

Current research activities aim at creating cheaper and more rugged designs of digesters for difficult terrains, investigating the use of weeds, algae and other wastes in the digester, development of microorganisms capable of digesting non-cellulose portions of biomass, seeking a better control and breeding of microorganisms, incorporating solar-powered heating for cooler climates and water saving mechanisms for arid regions, designing of more efficient biogas engines and turbines, creating easier techniques for gas storage and developing newer technologies for upgrading biogas to methane.

## **3.4 Solar photovoltaics**

Solar energy is the most abundant and inexhaustible of all the renewable energy resources. The average solar radiation incident over the South Asian countries varies from 4 – 7 kWh/day/m<sup>2</sup>. With most of these countries having about 300 sunny days in a year (Raman et al. 2012), it is but natural for them to explore the possibilities of harnessing the energy of the sun.

Solar Photovoltaic (SPV) devices convert sun light directly into electricity. High reliability and a lifetime of about 25 years for the solar panels are the most attractive features of SPV for its use in off-grid applications. Due to its high degree of modularity and scalability, SPV

technology can be used in a wide range of applications - from small solar lanterns up to kilowatt sized mini-grids. Its emission-free and silent operation makes it appealing for household applications. Absence of moving parts and its use of sun as a free fuel makes it virtually free to use during its entire lifetime, except for periodic replacement of battery. Even at the existing price levels, SPV can be a cost-effective solution for many remote locations that depend on kerosene lamps and diesel generators for lighting and power back-up.

### ***3.4.1 Overview of the technology***

PV technologies are broadly classified into crystalline silicon, thin Film, concentrating PV and emerging PV technologies. An SPV system usually consists of the following components:

- PV modules (which convert sunlight into electricity)
- Battery
- Charge controller
- Inverter
- Mounting structure
- Interconnections and other devices

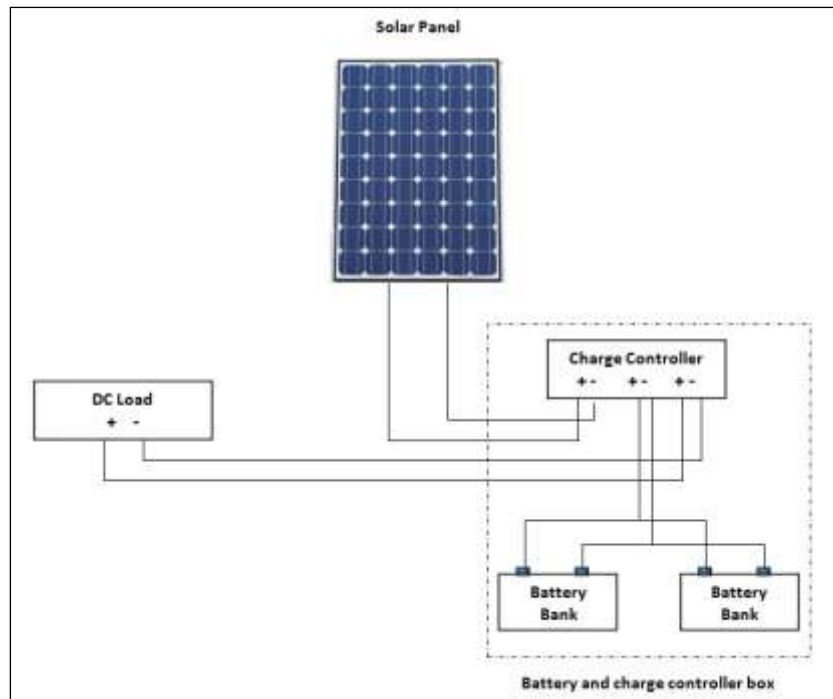
Several options of SPV technology are available for off-grid electrification:

- (i) Solar home systems (SHS),
- (ii) Solar battery-charging stations, and
- (iii) PV mini/micro grids

### ***3.4.2 Solar home systems***

These are systems that are designed to meet the power requirements of a small household. A solar home system consists of a PV module, a charge regulator, deep-cycle battery and optionally an inverter (when connecting to AC loads) (see Fig. 5). The charge controller which is a fundamental part of the SHS controls the energy inflow and outflow into and from the battery bank. SHSs are usually owned by the user; hence the user is responsible for all repairs, replacements and maintenance requirement throughout the useful life of the system (Chaurey and Kandpal 2010). The schematic of a typical solar home system is given in figure 5 below.

**Fig 5** Typical solar home system components



**Fig. 5** Schematic of a simple solar home system (Authors' Own sketch)

### Economics

The capital cost of a SHS varies based on type of system opted. The capital cost is directly related to the number of bulbs in the system. Table 5 gives typical capital costs SHS (TERI 2011).

**Table 5** Typical capital cost of SHS

Size of the system	Capital cost (US \$)
10 Wp module, two led lamps (2 W, 1 W)	100
12 Wp module, two led lamps (2 W, 1 W)	112
20 Wp module, two led lamps (3 W, 2 W)	187

### Benefits

- 

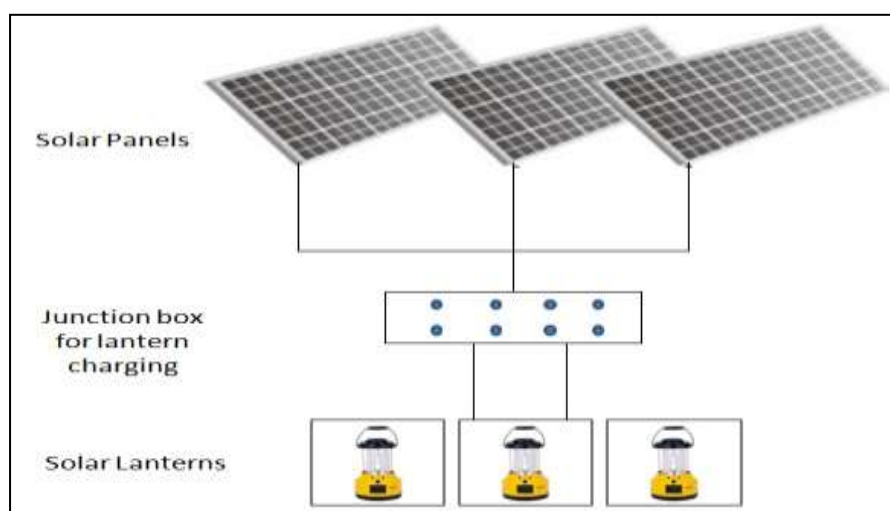
SHS is a DC system that generates stores and uses DC electricity usually at the same voltage levels throughout the cycle, thus it has higher system efficiency than PV mini-grid. Energy consumption and load management is within the control of user. No risk of fire smoke or smell as compared to the traditional energy sources.

### Current status

A several hundred thousand SHS are in operation in Africa, Asia and Latin America. It is estimated that 200,000 SHS are sold annually. A steady growth is expected over next few years (Goetzberger and Hoffmann 2005). In India, Sri Lanka and Bangladesh nearly 600,000, 125,000 and 750,000 SHSs had been sold as of 2010 respectively (REN21 Renewables 2011).

### 3.4.3 Solar battery-charging station

A large solar battery charging station (SCS) is typically set up at a central place in a village/hamlet. This station has battery bank charged from an array PV modules. A DC-DC converter is used to charge batteries of individual solar lanterns. Solar lanterns, due to their portability and versatility are a potential option for replacing kerosene lamps for domestic lighting applications. A solar lantern is a portable lighting device using either a CFL or LED based luminaire, housed in an enclosure made of plastic or metal that contains a re-chargeable battery and necessary electronics. The schematic of a typical SCS is shown in Fig. 6 below.



**Fig. 6** A typical solar charging station system

### Economics

The typical cost of a SCS depends on its capacity (numbers of households) and the lantern specifications. Table 6 shows typical costs of SCS including the cost of lanterns.

**Table 6** Typical cost of Solar charging station (TERI 2011)

Size of the system	Capital cost (US \$)
SCS for 50 households	2,222
Lanterns with a 2.5 W LED & 6 V battery	

SCS for 80 households	2,888
Lanterns with a 2.5 W LED & 6 V battery	

### Benefits

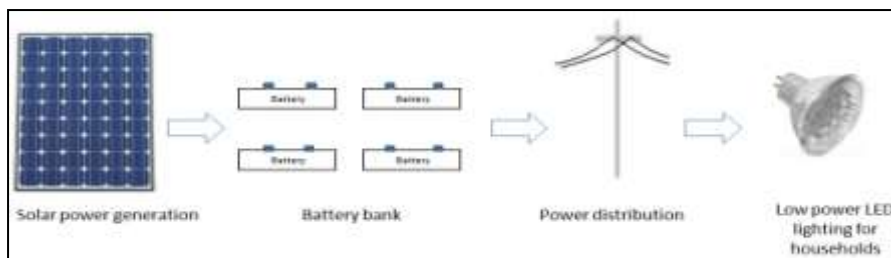
Solar lanterns are similar to kerosene lanterns and they are easily accepted by rural community. Easy to use, charging the lantern battery by paying fees is similar to buying kerosene. Users are not responsible for safety of PV modules. The consumer could either buy a lantern or pay fees of only charging or he can rent a charged lantern for a particular duration. The modular design of the SCS offers the advantage of need based capacity expansion of the charging station

### 3.4.4 PV mini/micro grid

Off-grid PV power plants, typically in the range of 1–500kWp, and with independent power distribution network (PDN). They usually supply 220 V 50 Hz three-phase or single phase AC electricity through low-tension PDN to households for domestic power, commercial activities (e.g. shops, video centres, computer aided communication kiosks, small grinders), and community requirements such as drinking water supply, street lighting and vaccine refrigeration (Chaurey and Kandpal 2010). A PV mini/micro grid essentially has:

- (i) Centralized electricity generating capacity mainly consisting of PV array,
- (ii) A battery bank to store the electricity,
- (iii) Power conditioning unit (PCU) consisting of junction boxes, charge controllers, inverters, distribution boards and necessary wiring/cabling, etc., all located within an appropriately constructed building and
- (iv) Power distribution network (PDN) consisting of poles, conductors, insulators, wiring/cabling; service lines, internal wiring and appliances to individual households.

Figure 7 shows a schematic of a PV mini grid.



**Fig. 7** Schematic of a PV mini grid

### Economics

The capital cost of PV mini grid system can be broken down to cost of each component. Percentage break-up of capital cost is shown in table 7.



**Table 7** Percentage break-up of capital cost (Raman P et al. 2012)

PV panels	53%
Battery bank	11%
Power distribution network	16%
Power conditioning unit	20%

The cost of the power distribution network varies depending upon topology. The typical cost of low-voltage distribution line is about \$3000 per km for the plains and it increases by 10 - 25% for remote, hilly regions. Thus by only considering the fixed cost of the solar PV micro grid system (without including the distribution cost) the solar PV array alone accounts for 63% of total cost, battery bank 13%, and power conditioning unit 24%. But the cost of the solar PV panels has declined significantly from \$3.5/Wp in 2009 to \$2/Wp in 2011; this has given a much needed boost for the adoption of SPV technology for off-grid electrification (Raman P et al. 2012).

#### *Current status*

The most common technology used for off-grid electrification in South Asia is solar PV mini grids. The mini-grids are typically in the range of 2 kWp to 150 kWp and provide AC electricity.

#### *Benefits*

- 

Possibility with grid interconnectivity in future is bright. It uses AC appliances, which are easily available in the market. Better monitoring of energy consumption is possible due to fixed hours of operation of the power plant at the generation level and use of individual meters. Plant requires less maintenance.

### ***3.4.5 Issues and barriers for SPV***

High investment cost of the solar panels and batteries is the most important barrier for commercial dissemination of this technology. The high cost of energy relative to the limited purchasing power of the rural households makes the electricity prohibitively expensive. With most rural households being able to pay only \$2 – \$3 per month for the electricity (Cust et al. 2007), it may not be financially viable to run a mini-grid on solar PV alone.

Difficulty in access to finance is another major hurdle that is preventing solar PV technology from large scale adoption. Most of the current off-grid PV installations in South Asia are from donor-assisted programmes. Many banks and financing institutions still perceive solar PV as an unproven technology and as a risky investment. This is exacerbated by the fact that financial institutions have difficulty finding well-informed advice about PV system financing. Limited availability of low wattage DC appliances is another factor that is currently restricting the technology to primarily lighting loads such as CFL and LED lamps. Replacement of battery-bank every 3 – 5 years can be an expensive affair if not planned for at the initial stages itself. Also, access to quality spares and trained technicians to undertake repair/replacement of equipment can be very difficult in remote regions

### **3.5 Small wind turbines**

Small wind turbines (SWT) are wind turbines which are smaller in size, simpler in construction and have lower energy output (typically up to 100kW (RenewableUK 2011)) as compared to the large commercial wind turbines found in wind farms. The two most common designs of SWTs are the horizontal axis wind turbines (HAWTs) and the vertical axis wind turbines (VAWTs). Most SWTs manufactured today are HAWTs with two or three blades and facing the wind. They generally have aero-elastic blades, lifetime bearings and direct drive generators. A vane helps it to point into the wind. Their simpler construction, rugged design and gear-less direct-drive mechanism ensures a higher efficiency, a longer life time and lesser maintenance expenses.

Unlike the larger wind turbines, installation of SWTs requires neither extensive infrastructure, nor special equipment for carrying the equipment. SWTs therefore have a great potential to provide electric power, especially in remote and hilly locations. However, due to the intermittent nature of the wind resource, SWTs are usually used in combination with other technologies such as Solar PV, diesel generators and energy storage systems. Common off-grid applications of SWT are for small homes, farms, institutions, communication systems, irrigation pumps and village mini grids.

#### ***3.5.1 Wind resources***

The energy produced by a SWT over a year depends critically on the average wind speed at the site. The wind resource at a site is usually measured by installing meteorological towers equipped with anemometers and wind vanes that measure the wind's speed and direction respectively. Where onsite measurement is not viable due to technical or economic reasons, secondary data is used from nearby reference stations such as airports, nearby meteorological towers or even from satellite measurements. While typical wind resource maps evaluate wind conditions typically at 50 metres height and above, setting up an SWT usually requires data at lesser than 30 metres height. This requires the data to be extrapolated to lower hub heights. Installations that are in a semi-urban or built environment would further require analytical tools to accurately assess the wind resource. With no such tools currently being available or affordable, for small wind developers, most

SWTs are currently installed in built-up environments based on approximate estimates of resource and power production.

The theoretical power generated by a small wind turbine (assuming negligible mechanical and electrical losses) is given by the equation below (Smallwindtips 2010).

$$P = C_p \times \frac{1}{2} \times \rho \times A \times V^3 \quad (7)$$

Where,

P = Power generated (in Watts)

$C_p$  = Power co-efficient of turbine, ranging from 0.25 to 0.45, (theoretical maximum = 0.59)

$\rho$  = Air Density (about 1.225 kg/m<sup>3</sup> at sea level)

A = Swept Area of Blades ( $\pi r^2$ ) (in m<sup>2</sup>)

V = Velocity of the wind (in m/s)

The power curve of a wind turbine gives the relationship of power generated and the wind speed. Most SWT manufacturers rate their turbines by the amount of power (rated power) that they can produce at a particular wind speed (rated wind speed). With no specific standard speed to define the power rating, there exists a possibility that the wind speed for which the SWT is rated would never be seen at the actual site of installation. Applying a combination of  $C_p$ , the swept area of turbine and the average wind velocity at a site can give us a more realistic estimate of the expected power output at a site.

### ***3.5.2 Technology overview***

Three main technological solutions are available using SWTs (EWEA 2009):

- Wind home systems
- Wind-PV hybrid systems
- Wind-diesel hybrid systems

#### *Wind home systems (WHS)*

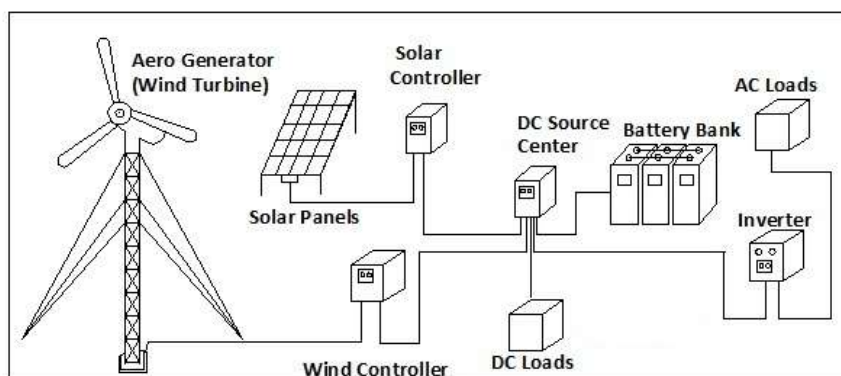
The WHS, similar to a Solar Home System, is designed to handle the power requirements of a household for lighting, TV, mobile charging and small household appliances. A larger sized WHS can also be used for community lantern/battery charging.

A typical WHS consists of a turbine mounted on the rooftop or on a tower, a charge controller, deep-cycle batteries and optionally a power conditioning unit (when connecting to AC loads). Turbines are usually of diameter less than 15 m and a rated power output of less than 7 kW. WHS are ideal for dwellings, schools, hospitals, telecom towers, water-pumps, etc in remote sites with wind speeds above 4 - 5 m/s. Unlike SHS that are very

widely available, WHS are still not popular in South Asia, with very few wind turbine manufacturers catering to this market.

#### *Wind-PV hybrid systems*

Most South Asian countries have a unique seasonal variation due to the monsoons. When the solar resource is low during the monsoon season, the wind speed is high and vice-versa. This creates an ideal situation for a SWT and solar hybrid. A diesel generator may also be used as an additional back-up source. Wind-PV hybrids [see Fig. 8], typically less than 50kW (EWEA 2009), can be used to handle the power requirements for farms, institutions, irrigation pump-sets, industrial applications, small commercial buildings, village electrification, etc.



**Fig. 8 Schematic of Wind-PV hybrid**

#### *Wind diesel hybrid*

When the power requirement is larger (up to 100kW) and when quality power cannot be delivered by the intermittent sources alone, a wind-diesel hybrid is used. The diesel generator handles most of the power requirement, with SWT being used to fill in whenever adequate wind is available. Batteries, if any, are used only to power supervisory controls and not for substantial storage. Wind diesel hybrid is a suitable solution for mini-grids in remote locations with adequate wind resource.

### **3.5.3 Economics**

The price of small wind turbines depends on its size, its design and whether it is operated in stand-alone or hybrid mode. The cost of a SWT installation includes the price of the complete system (wind turbine, tower, battery storage, power conditioning unit and wiring), in addition to labour charges for installation and permit charges in several countries. Other likely additional costs include those arising from resource assessment and feasibility studies. The typical cost for buying and installing a SWT ranges from about \$2500 to \$6000 per kW (AWEA 2009). In spite of the higher investment cost, their relatively lower operational costs

make the SWTs cost-competitive to conventional power in many off-grid or remote areas having a sufficient wind resource.

Though SWTs are designed for uninterrupted operation, they still require occasional cleaning and lubrication. In addition to the batteries, the turbine, guy wires, nuts and bolts, etc. require periodic inspection. The maintenance costs are primarily dependent on the availability of local spares and service. The amount of energy generated and hence the cost of energy is critically dependent on the average annual wind speed and the capacity factor (dependent on the frequency of wind) at the site of installation. The typical cost of energy for an off-grid SWT installation ranges from \$0.19 to \$0.34 per kWh (ESMAP 2007).

### ***3.5.4 Benefits***

SWTs are completely non-polluting and have no adverse environmental impact throughout its life time. They help remote off-grid and remote communities generate their own power and make them less susceptible to power interruptions from the grid. With proper site selection and sizing, SWTs can recover the initial investment within the first few years and produces virtually free electricity for up to 20 years with minimal servicing needs. Wind and solar resources complement each other and setting up a hybrid installation significantly increases the capacity factor for power generation. Unlike larger sized wind turbines, SWTs do not have land acquisition issues and do not require large infrastructure support to transport equipment. The SWT industry provides local employment for sales, installation and maintenance in the remote regions. Scope also exists for local manufacture or indigenization of the technology.

### ***3.5.5 Limitations and barriers***

Due to their low state of maturity and commercialization, current designs of SWT are relatively less efficient, more expensive to manufacture and produce lesser energy per kW when compared to their larger counterparts. With paucity of actual working installations, most customers are not aware of the technology and its benefits. Manufacturers of SWTs have limited resources to promote the technology. Hence SWTs may remain out of reach for most rural customers in South Asia without sustained government policies and funding. Also, in the absence of technology and policy for net metering, there will be little incentive for private players and co-operatives to adopt the technology for commercial gains.

Currently most manufacturers have their own performance rating criteria. This leads to concerns over the performance of the equipment at actual site. In the absence of testing to local or standard conditions, turbine components are prone to reliability concerns. Problems of noise and vibration observed in many small turbines can act as a major deterrent for rooftop installations and can be a major cause of customer dissatisfaction.

### ***3.5.6 Current status of the technology***

Small wind turbine technology is still in a nascent stage across the world in spite of the maturity attained on the development of the large and medium-sized wind technology for wind farms. While opportunities for off-grid energy access are making SWTs attractive to the developing world, feasibility to sell electricity to the grid through policies such as feed-in tariffs and net-metering is driving the sales in the developed world (AWEA 2011).

The US is the main market for SWTs in the world both in terms of consumption and production, with more than 100,000 small wind turbines in operation (EWEA 2009). As per a 2009 estimate by the American Wind Energy Association, there are approximately 250 companies manufacturing SWTs world-wide. Of these, 95 are based in the US. After the U.S., the U.K. and Canada are the largest markets for SWTs.

The South Asian market, though believed to be large, is yet to gain momentum. Realizing this huge untapped market, particularly in the off-grid segment, the small wind turbine manufacturers in the region are slowly organizing themselves to play a major role in the years to come (Windpowerindia 2010).

Globally, IEC standards exist for the safety requirements of SWTs (IEC61400-2) and other applicable IEC standards such as those for power performance or noise emissions measurements are borrowed from large wind technology. However, testing and certification of SWTs is not yet mandatory in most countries in South Asia and no national or regional standards exist.

Key challenges for the fledgling SWT industry in South Asia include better and affordable resource assessment, development of common industry standards, cost reduction with large scale commercialization and creating increased customer awareness with adequate government support.

## **3.6 Biodiesel**

Biodiesel is a natural, renewable fuel appropriate in any situation where petro-diesel is used. Biodiesel can be used in ordinary diesel engines. It is a clear amber-yellow liquid with a viscosity similar to petro-diesel. Biodiesel can be used alone, or blended with petro-diesel. Biodiesel can be produced from feed stocks such as: plant oils, waste oils, using either pressure extraction or transesterification with alcohol. Biodiesel unlike petro-diesel is biodegradable and non-toxic, and it significantly reduces toxic and other emissions when burned as fuel.

### ***3.6.1 Resources availability***

The most common feed stocks for biodiesel are rapeseed, sunflower, soybean, palm oil, animal fats and used frying oil. In South-Asia, due to paucity of edible oils, only non-food feed stocks are being recommended (Verma and Sharda 2005). India has rich and abundant

forest resources with a wide range of plants and oilseeds. Non edible oils such as rice bran, sal, neem, mahua, karanj, jatropha, etc. are easily available in many parts of the world including South-Asia (Satish 2006). Non-edible oil sources of India, their potential and current utilization is shown in table 8 .

**Table 8** Non-edible oil sources of India

Oil	Botanical name	Potential (tons/year)	Utilized (tons/year)	% utilization
Rice bran	Oryza sativa	474,000	101,000	21
Sal	Shorea robusta	720,000	23,000	3
Neem	Melia azadirachta	400,000	20,000	6
Karanj	Pongamia glabra	135,000	8,000	6

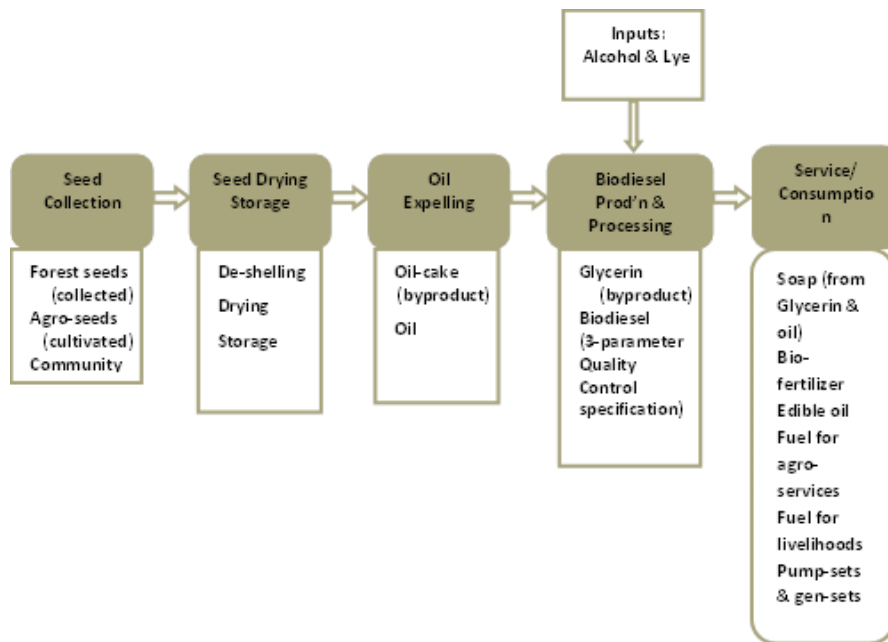
Source Satish 2006

### 3.6.2 Overview of technology

Biodiesel is generally produced by transesterification process. Oil is reacted with alcohol in presence of a catalyst to produce biodiesel and glycerol. The alcohols of choice for making biodiesel are methanol or ethanol. The catalysts of choice are sodium hydroxide, also known as lye in US, and potassium hydroxide. These are available in market for purchase, or can be produced locally with ease. A cursory look at the literature relating to biodiesel reveals the following simplified relationship for the prediction of biodiesel made from fats and oils.

100 kg of oil + 10 kg of methanol → 100 kg of biodiesel + 10 kg of glycerol(3.8)

The basic technology is shown in Fig. 9.



**Fig. 9** Basic technology for production of biodiesel

Step by step biodiesel production process:

- (i) Boil vegetable/animal oil, leave it to precipitate
- (ii) Take alcohol 25 % of boiled oil
- (iii) Add lye, weighing 1 % of oil, add it to alcohol
- (iv) Mix warmed oil and stir
- (v) Transesterification reaction takes place
- (vi) Leave the batch and let glycerine separate
- (vii) Clean biodiesel to reduce amount of alcohol
- (viii) Biodiesel percolation using 5-micron filter

### ***3.6.3 Rural electrification using bio-diesel***

Many non-edible oil-seeds grow in forests, wasteland, and can be cultivated in unused land in the village premises. These non-edible oil-seeds can be used to produce biodiesel by the simple process explained above. Biodiesel production does not require economy of scale. There is no minimum size for a biodiesel facility. Small decentralized biodiesel facilities do not require dedicated technical staff support; they can be operated by locally trained non-technical staff. Thus biodiesel is a renewable way of meeting rural energy demands. Biodiesel can be produced in a required quantity and used to run a diesel generator set. The generated electricity could be stored in a battery bank, and used to charge lantern or could supply power through a DC mini grid. Although it is recommended that biodiesel must not be used for sole purpose of electrification, it must be used for other applications like pumping drinking water, etc.



### ***3.6.4 Economics***

The rapeseed oil derived biodiesel, in 1992 cost 186 % of the price of conventional diesel. An evaluations of cost from US soybean and sunflower in 2005 concluded that biodiesel cost were 2.8 fold those of conventional diesel. The production cost depends on production route. When we talk about biodiesel for rural electrification, the simplest way of producing biodiesel must be followed. Sale of glycerol would reduce cost of production by approximately 6 % (David 2010). Sale of glycerol covers not only cost of alcohol and catalyst, but labour and the energy input as well. Small decentralized biodiesel plants of capacity 45 – 1800 tons/year would cost around US \$ 1,000 – 40,000 respectively (Satish 2006).

### ***3.6.5 Benefits***

Biodiesel is non-toxic. It provides domestic renewable energy supply. Biodiesel fuel burns up to 70 % cleaner with 93 % lower total HC, 50 % lower CO and 45 % lower particulate matter in comparison with conventional diesel fuel. Biodiesel could be produced and used as and when needed, the energy can be stored in form of liquid fuels (advantage over other renewable energy technologies). Utilization of by-products of transesterification such as glycerol and oil cakes would bring extra revenue.

### ***3.6.6 Limitations and barriers***

**NO<sub>x</sub> emissions** are generally higher (0-10 %) but can be reduced by additive like butyl peroxide (DTBP) or by retarding the injection timing. Biodiesel can't be directly used in engines having components made of nitrile rubber, as biodiesel dissolves it. Thus, **engines need retrofitting**, replacing nitrile rubber by fluorocarbon rubber. **Engine performance is less than that of diesel** by 8 – 15 %, because of low energy content. Concerns have been raised in the past regarding the impact of biofuel production on the prices of agricultural commodities. **Land and water constraint:** One of the main barriers for biodiesel is that rural people have limited land and water which they use for agriculture of edible substance.

### ***3.6.7 Current status of the technology***

Rapeseed oil methyl ester was the first type of biodiesel fuel produced commercially in 1988. Tremendous progress has been made in the past two decades. Actual production in the world rose from about 10,000 tons in 1991 to about 2,800,000 tons in 2003 (Verma and Sharda 2005). In 2010, the annual production of bio-diesel was at 19 billion litres (REN21 Renewables 2011). In principle there are two approaches that can be taken to secure the wide use of biodiesel in the national fuel market: whereas German law prefers a biodiesel to be used in the pure form, in France biodiesel blended with fossil fuels carries the tax advantages (Planning and installing bioenergy systems 2005). At present, USA uses 50

million gallons and European countries use 350 million gallons of bio-diesel annually. France is the country which uses 50% of bio-diesel mixed with diesel fuel (Murugasen et al. 2009). Biodiesel based rural electrification has been attempted in various places in South Asia and Africa. Successful example can be seen in West Africa, Odisha in India and many more.

Each of the RETs discussed above vary immensely in terms of the resources required, their initial and operational costs, their levels of technical maturity and their perceived social and environmental benefits. Table 9 lists some of the relative strengths and weakness of the technologies discussed.

**Table 9** Relative strengths and weakness of technologies

Technology	Capital cost	Operational cost	Technology maturity	Resource availability	Social and environmental benefits
Micro hydro	Very high	Very low	High	Medium	Medium
Biomass gasification	Low	Very high	Very low	High	High
Biomethanation	High	Low	Low	Very high	Very high
Solar PV	Very high	Medium	Very high	Medium	Medium
Small wind	Very high	Medium	Low	Medium	Medium
Biodiesel	Medium	High	Very low	Low	Medium

## 4 Conclusions

Despite the abundance of renewable energy resources in South Asia, a significant portion of the population does not have access to modern energy services. The renewable energy solutions discussed show promising potential to address this problem. However, no single technology is capable of either harnessing the diverse energy resources available or addressing the varied nature of the energy services required. Therefore, a faster development and wider deployment of the full range of technologies is essential for universal energy access to be achieved.

Each of the technologies is in a different stage of evolution and requires different stimuli for its development. Research for further reduction in the capital cost and development of innovative financing or pricing mechanisms could make the costlier technologies such as Micro hydro and Solar PV more attractive even in the developing countries. The less mature technologies, on the other hand, require an extensive focus on applied research and a localized innovation strategy to promote their accelerated diffusion. In the interim, new hybrid solutions and smart mini-grids can be adopted to effectively utilize the core strengths of each of the RETs in addition to maintaining diversity in supply options for decentralized electrification.

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## **Acknowledgement**

The activities reported in this report are funded by an EPSRC/ DfID research grant (EP/G063826/2) from the RCUK Energy Programme. The Energy Programme is a RCUK cross-council initiative led by EPSRC and contributed to by ESRC, NERC, BBSRC and STFC.

## **Disclaimer**

The views expressed in this report are those of the authors and do not necessarily represent the views of the institutions they are affiliated to or that of the funding agencies.



## OASYS South Asia project

The Off-grid Access Systems for South Asia (or OASYS South Asia) is a research project funded by the Engineering and Physical Sciences Research Council of UK and the Department for International Development, UK. This research is investigating off-grid electrification in South Asia from a multi-dimensional perspective, considering techno-economic, governance, socio-political and environmental dimensions. A consortium of universities and research institutes led by De Montfort University (originally by University of Dundee until end of August 2012) is carrying out this research. The partner teams include Edinburgh Napier University, University of Manchester, the Energy and Resources Institute (TERI) and TERI University (India).

The project has carried out a detailed review of status of off-grid electrification in the region and around the world. It has also considered the financial challenges, participatory models and governance issues. Based on these, an edited book titled “Rural Electrification through Decentralised Off-grid Systems in Developing Countries” was published in 2013 (Springer-Verlag, UK). As opposed to individual systems for off-grid electrification, such as solar home systems, the research under this project is focusing on enabling income generating activities through electrification and accordingly, investing decentralised mini-grids as a solution. Various local level solutions for the region have been looked into, including husk-based power, micro-hydro, solar PV-based mini-grids and hybrid systems. The project is also carrying out demonstration projects using alternative business models (community-based, private led and local government led) and technologies to develop a better understanding of the challenges. It is also looking at replication and scale-up challenges and options and will provide policy recommendations based on the research.

More details about the project and its outputs can be obtained from [www.oasyssouthasia.dmu.ac.uk](http://www.oasyssouthasia.dmu.ac.uk) or by contacting the principal investigator Prof. Subhes Bhattacharyya ([subhesb@dmu.ac.uk](mailto:subhesb@dmu.ac.uk)).

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