# RETookit Technology Module

## Overview

This chapter provides brief technical summaries, cost estimates, resource requirements, siting and environmental issues, technical standards, equipment specifications and other requirements for small hydropower, wind power, biomass power plants, geothermal power plants, solar and hybrid systems. The information contained under each type of renewable energy is intended to provide necessary background information for grid-connected, mini-grid as well as stand-alone systems. Considerations specific to mini-grids are mentioned in the small hydropower and biomass sections, as well as in hybrid systems section. Specific wind energy and solar energy information for stand alone systems is provided in the wind energy and solar energy sections, respectively.

The World Bank performed an economic comparison of 22 power generating technologies based on 2005 costs. The objective was to characterize the technical and economic viability of electricity generation technologies (both renewable and conventional) to serve rural, peri-urban and urban populations in developing countries. This work provides a capital cost comparison and an electricity cost comparison for renewable energy and conventional energy technologies.[1]

## Small Hydropower

Hydropower is currently the most used modern form of renewable energy and is derived from natural waterfalls, dams, tidal basins, ocean waves, rivers & streams. Hydropower from large dams and tidal basins requires strict safeguards to avoid significant environmental and social impacts such as flooding large tracts of arable land, displacing people and wildlife, and drastically changing the local ecosystem. Small hydropower projects generally avoid these problems and can serve rural energy needs.

There is no universally accepted definition of small hydropower, but in general it means that there are low environmental impacts, it uses a run of river design, or it has a small impoundment with little flooding of land. The definition of the upper capacity limit for small hydropower varies by country jurisdiction and ranges from 10 MW to 50 MW. In general, however, commonly accepted thresholds for Hydropower Systems are those outlined below.

| **Commonly Accepted Thresholds For Hydropower Systems** | |
|---|---|
| Pico-hydropower | < 5 kW |
| Micro-hydropower | 5 kW - 100 kW |
| Mini-hydropower | 100 kW – 1 MW |
| Small hydropower | 1 MW - 10 MW (- 30 MW) |

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[1] This study, "Technical and Economic Assessment of Off-grid, Mini-grid and grid Connected technologies," completed in 2006 using 2005 data. Since that time, equipment costs as well as fuel costs have risen steeply. Hence the results should be considered indicative only. The World Bank ESMAP unit is currently (May 2008) conducting investigation of the equipment costs for some power generation technologies. This data, coupled with current fuel cost information needs to be used to update the results of the previous study.

| | |
|---|---|
| Medium and large hydropower | > 10 MW (> 30 MW) |

## Global Status

Small Hydropower capacity and generation statistics published in the REN21 Global Status Reports include plants between 1 and 10MW (and plants up to 50 MW in China and 30 MW in Brazil, as these nations define and report small hydropower based on those thresholds). According to the 2007 Report, worldwide installations of small hydropower stations reached a capacity of 73 GW in 2007[2]. The largest share of these installations is in China, a total installed capacity of 41 GW. Other market leaders in the development of small hydropower stations are Brazil, Russia, Canada and the US and EU-25 countries.

## Technical Summary

A typical run-of-river small hydropower plant is illustrated in the figure below. Water is removed from a river at an intake structure, which may be a simple canal outlet as shown, or a small diversion may be required to redirect water into a canal leading to a forebay. The canals can often be several kilometers in length and may even involve a tunnel. At the forebay, or headworks, the water goes into a penstock, or large pipe, leading to the powerhouse where the hydro turbines are located (Figure. 5.1). After passing through the turbines, the water travels through a tailrace to re-enter the river.

There are several issues that are inherent to many small hydropower stations. First, the scale of electricity production is small, and the cost for design, engineering, and project financing can be high relative to the overall cost of the project. Second, there is often no reservoir, and the station output is dependent on the water flow in the river, and that can vary significantly between the high water seasons and the low water seasons.

## Resource Assessment

Information on mini-hydro resources must generally be obtained through local sources, such as forest and water resource agencies. Several years worth of hydrological data are needed to ensure that long-term financial calculations are based on the average hydrological year. Very often, mini-hydro resources are seasonal and highly dependent on rainfall in the local watershed, and the system performance can vary significantly from one year to the next. Therefore, the accuracy of the financial assessment will depend on the quality of the hydrological data available.

**Figure 5.1. Typical Run-of-the-River Small Hydropower Plant**

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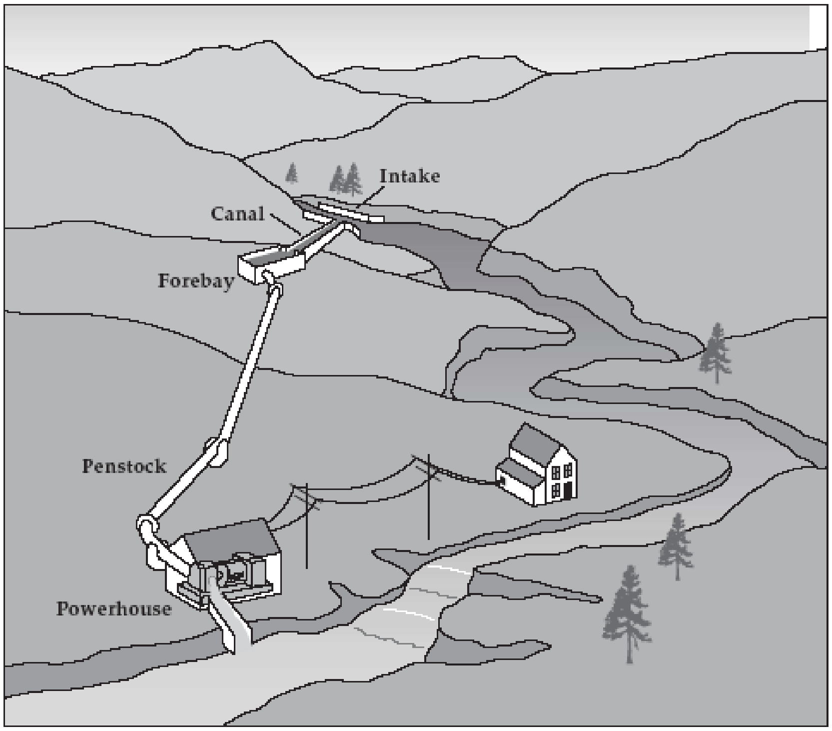
[2] REN21. 2008. "Renewables 2007 Global Status Report" (Paris: REN21 Secretariat and Washington, DC:Worldwatch Institute). http://ren21.net/pdf/RE2007_Global_Status_Report.pdf



An international database of small hydropower resources is developed and maintained by the Small Hydropower Annex of the IEA's Implementing Agreement for Hydropower Technologies and Programs. The objective of the database is to facilitate the development of new small hydro projects of more than 50 kW and less than 10MW installed capacity. The web site provides data for potential and developed sites, GIS searching capabilities, country profiles, international contacts for small hydro, and a world resource atlas.

**Cost and Performance**

The capital cost for most small hydropower projects in 2005 ranged from $1400 to 2200/kW installed power[3]. Costs are very site-specific, and careful investigation of the hydrological resource, the geology and civil works requirements, and the electro-mechanical equipment requirements are needed to develop an accurate cost estimate. Operating and maintenance costs in 2005 ranged between 0.7 and 0.5 US cents/kWh for small hydropower facilities with capacity factors in the range of 30 to 45%.[4] The operating life of most facilities is over 40 years.

The assessment of possible small-hydropower project sites represents a relatively high proportion of overall project development costs. A high level of experience and expertise is generally required to accurately complete an assessment. However, over the past two decades numerous methodologies and software assessment packages have been

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[3] Technical and Economic Assessment of Off-grid, Mini-grid and Grid Electrification Technologies. December 2007, ESMAP Technical Paper 121/07

[4] Ibid.

developed in an attempt to reduce the time and cost required for comprehensive assessments. One of these tools is provided by RETScreen International.

### Small Hydropower for Mini-Grid Systems

Hydro-based mini-grid systems most often use mini-hydro or micro-hydro power plants. Mini- and micro-hydro plants are often the run-of-river type and generally do not involve a dam with impoundment of water. Therefore, they often avoid the kinds of detrimental environmental and social impacts that can be problems for larger hydropower systems.

#### *Technical Summary*

A mini-grid village hydro system is an isolated water-driven power supply intended to provide a village with energy for various applications such as:

- Electricity for lighting and appliances (radio, TV, computer, etc), in homes and public buildings such as schools and clinics,
- Electrical or mechanical power for local service and cottage industries,
- Electrical or mechanical power for agricultural value-adding industries and labor saving activities, and
- Electricity for lighting and general uses in public spaces and for collective events.

Village hydro systems are comprised of three elements:

- Civil works: these consist of diversion works, channels and piping to convey river, stream or spring water to the power generation equipment, the power house building and water exit channel
- Power generation equipment: this consists of a turbine, a drive system linking the turbine to a generator and/or mechanical devices, a generator, a generator controller and switchgear
- Power distribution system: this involves distribution of electrical power by one or more main distribution lines to central points, then by sub-distribution lines and consumer service connections to consumption points. Very small village systems may contain a battery charging system to provide energy storage, voltage stability and services to remote customers.

#### *Cost, Performance and Project Risks*

The costs of mini-hydro power systems vary considerably as the result of many site-specific design and performance related factors. Mini- and micro-hydro systems are most likely to be financially sustainable if they have a high load factor, a financially sustainable end-use, and costs are contained by good design and management. The greatest project risks are not technical, but business-related. Management of the installation, including the setting and collection of tariffs that keep pace with inflation is critical for project sustainability.

### *Feasibility Study Tools*

Guidelines and design aids for the assessment of micro-hydro projects have been developed by the Alternative Energy Promotion Center of Nepal under the Energy Sector Assistance Programme supported by the Danish International Development Assistance (DANIDA). The guidelines and aids provide a basis and tools for performing detailed feasibility studies, including technical design, for micro-hydro projects between 3 kW and 100 kW.

### *Technical Specifications*

A set of Village Hydro Project Specifications were developed under the Bank's Sri Lanka Energy Services Delivery (ESD) Project. The specifications consist of the following seven sections:

(Each item below is a link to a document in the World Bank document library.)

1. Introduction
2. General Requirements
3. Civil Works
4. Mechanical Components
5. Electrical Components
6. Battery Distribution
7. Line Distribution

These specifications were intended to provide a fast and practical system for checking and promoting the viability of schemes being considered for credit assistance. They are not intended to provide comprehensive guidance to design calculations, or to operation, maintenance, management, and fault finding procedures. The specifications should therefore be used in conjunction with other documents.

## WIND

Wind resources which can be exploited economically exist on land and off-shore, mostly outside tropical areas. In tropical areas special climate phenomena like monsoons or mountain winds are necessary to make the use of wind power economic for grid-connected applications. Wind power is generated by large modern wind turbines, and it is currently the fastest growing renewable energy technology worldwide. Development of modern wind power for large scale electricity generation started in the 1970s energy crisis, and over 2000 MW were installed in the 1980s, mostly in California. In the 1990 and 2000s there have been major installations in Europe, North America, China, India and many other areas.

### Global Status

Annual installations of wind turbines have grown from 200 MW in 1990 to about 20,000 MW in 2007 for an annual growth of about 27%[5]. The global annual market in 2007 was greater than $37 billion with a cumulative installed capacity of over 94,000 MW worldwide. As of the end of 2007, the top five countries in terms of installed capacity were Germany with 22.3 GW, US with 16.8 GW, Spain with 15.1 GW, India with 8 GW and China with 6.1 GW.

Wind development continues in key emerging market countries. At the end of 2007, China had a total installed wind energy capacity of over 6,000 MW, countries of the European Union had total installed capacity of over 57,000 MW, with Spain leading the market with a total installed capacity of 15,000 MW[6]

## Technical Summary

Wind is a variable but highly regular and statistically predictable resource. Good sites have average annual wind speeds of 6.0 meters/sec (13 miles/hr) or greater, and accurate, preferably multi-year wind speed data of a high quality is critical to determining the economic feasibility of a wind project.

Wind is a modular technology and wind farms can be erected quickly. Most common wind turbines in commercial grid-connected operation average 1.5 W in peak power capacity. As shown in the Figure 5.2. below[7], wind turbine sizes have increased dramatically in recent years, and this technology development has resulted in continued improvements in efficiency and reduced costs. The newest trend is the development of turbines for offshore deployment.

Wind turbines are very reliable and have guaranteed availabilities greater than 95 percent. Wind farm capacity factors range from 20 to percent at average wind sites to more than 40% at the best sites. Possible environmental issues include, visual, cultural, land use, and bird issues, and noise. Planning approval and environmental assessment are usually necessary.

While wind is very close to being strictly cost-competitive with conventional power generating technologies, its market growth is still mainly driven by special support schemes in OECD countries.

**Figure 5.2.**

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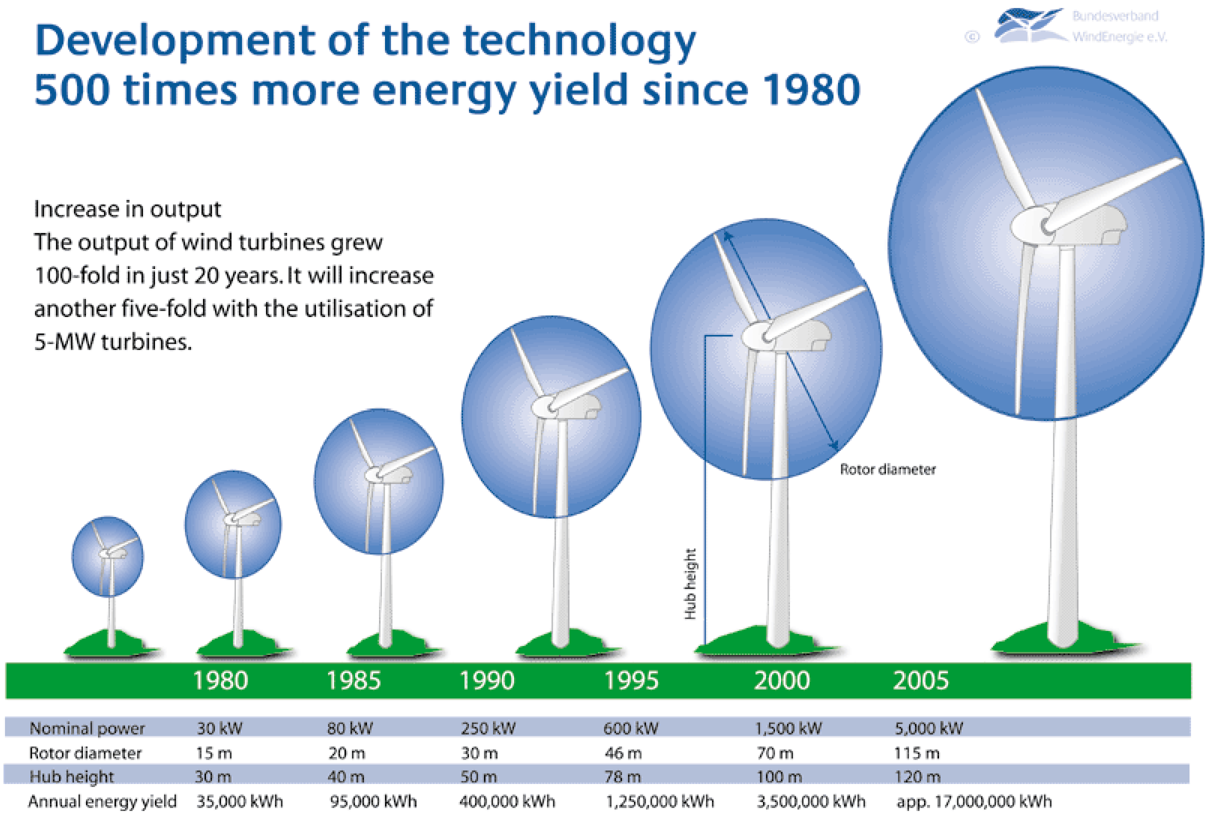
[5] Global Wind Report:2007, Global Wind Energy Council. http://www.gwec.net/uploads/media/Global_Wind_2007_Report_final.pdf

[6] Ibid.

[7] Renewable Energies: Innovation for the future. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany, April 2006. http://www.bmu.de/files/english/renewable_energy/downloads/application/pdf/broschuere_ee_innovation_eng.pdf


Development of the technology
500 times more energy yield since 1980

Increase in output
The output of wind turbines grew 100-fold in just 20 years. It will increase another five-fold with the utilisation of 5-MW turbines.

| | 1980 | 1985 | 1990 | 1995 | 2000 | 2005 |
|---|---|---|---|---|---|---|
| Nominal power | 30 kW | 80 kW | 250 kW | 600 kW | 1,500 kW | 5,000 kW |
| Rotor diameter | 15 m | 20 m | 30 m | 46 m | 70 m | 115 m |
| Hub height | 30 m | 40 m | 50 m | 78 m | 100 m | 120 m |
| Annual energy yield | 35,000 kWh | 95,000 kWh | 400,000 kWh | 1,250,000 kWh | 3,500,000 kWh | app. 17,000,000 kWh |

## Resource Assessment

Having high-quality wind resource data is extremely valuable to a wind energy project developer or potential wind energy user because it allows them to choose a general area of estimated high wind for more detailed examination. Several wind resource databases and maps have been developed in recent years for such purposes.

In the US, NREL identifies and gathers data for wind resource maps of the United States and foreign countries. This information is maintained by NREL in the National Wind Technology Center, which provides the following wind resource data and links:

- Wind Resource Bibliography
- National Climatic Data Center Wind Speed Data
- Wind Maps of the United States including seasonal wind maps
- Wind Maps for all 50 State and US territories
- International Wind Resource Maps and databases for 14 countries
- Wind Resource Assessment Handbook
- Wind Energy Potential paper, which describes how much electricity could be generated from wind in the United States.

In Europe, the Database of Wind Characteristics is compiled and maintained by the Technical University of Denmark (DTU) together with Risø National Laboratories. This database contains four different categories of wind data: time series of wind characteristics, time series of wind turbine responses, wind resource data and wind farm data.

The time series are primarily intended for wind turbine design purposes and the resource data can be used for siting analysis. The database provides wind speed measurements, measured under different conditions and terrain types at 55 different locations inside Europe, Egypt, Japan, Mexico, Costa Rico and United States.

The Solar and Wind Energy Resource Assessment (SWERA) provides information about solar and wind energy resources in a number of countries around the world. Products include data on wind and solar energy potential, plus detailed country energy analyses. SWERA is a UNEP (United Nations Environment Programme) project with co-financing from GEF. The goal is to provide solar and wind energy assessments to potential investors and the public to promote more effective use of alternative energy resources.

## Cost, Performance and Project Risks

Installed costs for on shore wind farms typically range between \$1800/kW and \$2400/kW installed[8], and for off-shore wind farms the cost is typically about 50% higher. It should be noted, however that wind turbines are generally not priced per MW but by swept rotor area, since the annual energy production at any given location is largely proportional to the swept rotor area, whereas the production varies only marginally with the size of the generator of the turbine.

Operating and maintenance cost typically run about 1.5-2 US cents/kWh.[9]

The cost of electricity from modern grid-connected wind farms ranges from 7-12 US cents/kWh depending on the site and the strength of the wind resource. These wind farms generally must compete against conventional grid power options, which vary widely depending on whether diesel, gas, coal or other primary energy sources are the alternative. Wind power will generally replace generation from the more expensive marginal medium load generating units on the grid.

Commercial wind turbines have a proven availability factor greater than 95 percent and have very low technical risk if supplied by large, mainstream manufacturers. However, wind farms usually require local permits and project development risks often include the need for an environmental impact assessment to mitigate any environmental issues such as visual, noise, land use, cultural problems, or impacts on birds. Finally, a power purchase agreement is necessary for grid-connected wind farms, and delays in these processes often constitute the greatest risk to a developer.

There is a potential for local manufacturing of many wind turbine components depending upon the volume of the order and the technical capacity of the country. Generally it is not economic to manufacture, say, towers locally unless orders are above 50 to 100 turbines. Relatively simple components include the steel towers, transformers, wiring and nacelle housings. All component manufacturing requires ISO 9000 certification of manufacturing quality control systems in order to comply with certification standards. Highly machined

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[8] Typical investment including grid connection and substation is around 2400\$/kW installed. These figures are based on the market situation and exchange rates in May 2008.

[9] The figure includes major overhauls such as replacement of a major component such as a gearbox or generator after 12-15 years. Cost level and exchange rates of May 2008

components include the generator, gearboxes and bearings, and are normally made by companies with a very substantial experience. The most sophisticated components include the control systems and blades. These are generally imported, but for large orders for a durable market over several years there may be scope for local manufacturing of rotor blades, which is generally a rather labor intensive process.

## Standards and Certification

Design standards and type certification assure that a wind turbine is sound, safe, and has been manufactured and constructed with good engineering practice. Wind turbines have to be designed for the wind climate in which they are to be installed, i.e. specifications vary depending on e.g. mean wind speeds, turbulence and maximum wind gusts on the proposed site. It is good business practice always to require that wind turbines be type certified as fit for purpose on the site in question. This certification should be in accordance with the latest version of the International Electrotechnical Commission (IEC) 61400 standards series and the certification must be issued by autonomous accredited organizations such as Det Norske Veritas (DNV) or Germanischer Lloyd. Having internationally recognized standards creates a level playing field in the market place and assures that every turbine meets a minimum level of safety.

International standards for wind turbines are developed by the working groups of Technical Committee-88 (TC-88) of the International Electrotechnical Commission (IEC), the recognized international body for standards development activities. These standards cover the following topics, and more information on them can be found at the American Wind Energy Association (AWEA) web site. The standards can be purchased directly from IEC or through any national standards institute.

- IEC 61400-1 Wind Turbine Safety and Design
- IEC 61400-2 Small Wind Turbine Safety
- IEC 61400-11 Noise Measurement
- IEC 61400-12 Power Performance
- IEC 61400-13 Mechanical Load Measurements
- IEC 61400-21 Power Quality
- IEC 61400-22 Wind Turbine Certification
- IEC 61400-23 Blade Structural Testing
- IEC 61400-24 Lightening Protection
- IEC 61400-25 Communications for Monitoring and Control of Wind Power Plants

New standards are under development by IEC, IEEE, and the International Organization for Standardization (ISO) which will update or create technical requirements and design techniques.

Several certification programs have been established, presently mostly in Europe.

In Europe, DNV Wind Turbine Certification in Denmark provides certification services for both wind turbine types as well as on-shore and off-shore wind farms. DNV offers certification worldwide, and holds a wide range of national accreditations. In the US, NREL has set up a certification system in partnership with Underwriters Laboratories (UL).

Because the present standards used in the certification and design evaluation of wind turbines contain a lot of sub-optimal compromises the European wind turbine certification (EWTC) guidelines were developed to provide a common practice in order to overcome the different interpretation of technical and safety requirements for wind turbines. The guidelines are to be used together with the IEC standards and other Certification Regulations used by the Certifying Bodies. The ultimate objective is to work towards a uniform wind turbine certification.

## Grid Interconnection

Much work has been done to develop US and European interconnection requirements and standards. IEC Standards and Definitions do exist and most wind turbine manufacturers have technical interconnection criteria called "Electric Grid Data". In the US, the National Wind Coordinating Collaborative[10] (NWCC) is attempting to standardize interconnection procedures in US, and the US Federal Energy Regulatory Commission (FERC) Rule dated 23.07.2003 promotes an interconnection standard for large (>20 MW) wind plants. However, there are many site-specific aspects to grid interconnection, and the process for developing grid interconnection is illustrated in Figure 5.3 below[11].

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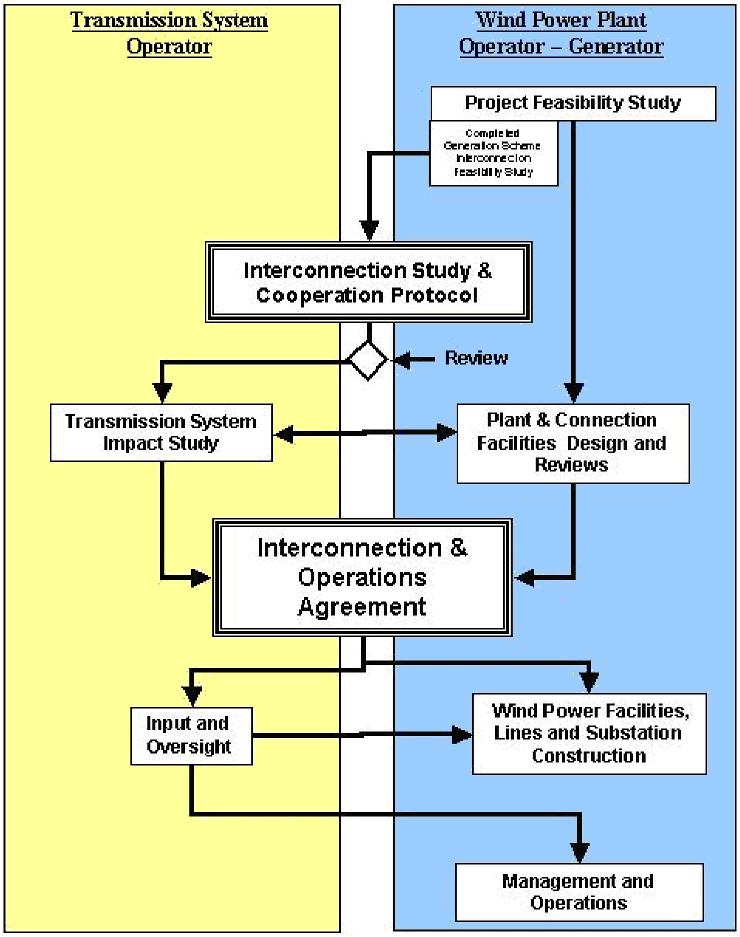
[10] United States, National Wind Coordinating Committee, "Interconnection Issue Brief," September 2003. http://www.nationalwind.org/publications/transmission/transbriefs/Interconnection.pdf

[11] Grid Interconnection And Operation For Wind Power Plants in Russia, IFC/GEF http://iris37.worldbank.org/domdoc/PRD/Other/PRDDContainer.nsf/DOC_VIEWER?ReadForm&I4_KEY=0CAEAB9ED9D6672385256D8A004CDDD9E452D4E6717BE271852570D2006396A9&I4_DOCID=461CAF8068581C79852570D700607F57&

**Figure 5.3. Wind Power Plant Grid Interconnection Process.**



Various aspects of the grid interconnection process can be further explored through the following links:

- US Department of Energy Wind and Hydropower Interconnection Standards
- PJM Generation and Transmission Interconnection Studies, Main Manual,

## Variability of generation

Wind is a variable resource, and compared to conventional generators, a wind plant's output is relatively uncontrollable in an upwards direction. Wind production can always be curtailed remotely by the grid operator if the proper communication equipment and agreements are in place. However, as wind becomes a larger share of total generating capacity, issues related to its integration with utility grid operations and markets are becoming increasingly important. On the other hand, if wind farms are dispersed geographically, then their output will have a low degree of correlations, and variations in generation will tend to cancel out between wind farms.

Integration of wind is qualitatively different from that for other types of generators because wind output depends on whether, when, and how hard the wind blows. Because of these characteristics and because electric-system operators have little experience with wind facilities, considerable disagreement can exist regarding the costs of integrating wind into electric grids.

As the total contribution from wind becomes significant (generally believed to be at about 10% to 15% of total system load) it can no longer be considered to be largely invisible (and therefore cost free) to a large electric grid. On the other hand, every unscheduled megawatt movement of a wind farm does not necessarily need to be offset, megawatt for megawatt, by some other resource. In many climates wind generation is often positively correlated with electricity demand, and if this is the case, then integration of large amounts of wind power will be easier.

New quantitative methods for analyzing the integration of wind resources into a large electric grid have been developed and should be applied when the total contribution from wind becomes significant[12]. These analyses integrate real-time data on both wind resources and the load variability of the electric grid. It also integrates the impacts of the associated short-term competitive market for wholesale electricity, if such a market exists.

A key feature of the new analytical approach is its *integration* of wind with the overall electrical system. It is essential that the uncontrollable and variable nature of wind output is not analyzed in isolation. Rather, as is true for all loads and resources, the wind output is *aggregated* with all the other resources and loads to analyze the net effects of wind on the power system. It makes no sense to attempt to counterbalance the variations in wind production using other generating technologies, what is important is to balance the overall supply and demand in the grid.

Aggregation is a powerful mechanism used by the electricity industry to lower costs to all consumers. Such aggregation means that the operator need not offset wind output on a megawatt-for-megawatt basis. Rather, all the system operator need do, when unscheduled wind output appears on its system, is maintain its average reliability performance at the same level it would have without the wind resource.

The results developed with this new analytical method suggest that a system operator need not acquire regulation and intra-hour-balancing resources to counter every change in output from a wind farm. The system operator should treat wind the same way that any time-varying load or generator should be treated, regardless of whether there is a competitive wholesale electricity market or not.

The analysis must be performed for specific wind power plants and the electric grids they supply. However, generalized results from early analyses indicate that:

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[12] Interactions of Wind Farms With Bulk-Power Operations and Markets. Project for Sustainable FERC Energy Policy. September 2001. http://cwec.ucdavis.edu/rpsintegration/library/Wind%20farms%20and%20bulk-power%20interactions%20Sep01%20Hirst.pdf

- Forecasting wind output ahead of time (e.g., in an hour-ahead energy market) yields lower system impacts than having the wind appear entirely as intra-hour imbalance energy.
- There is significant benefit to accurately forecasting wind plant output one hour ahead, and that this benefit increases as the size of the wind facilities increase. These benefits suggest that the value of accurate forecasts of wind output could be substantial.
- The average cost of integrating wind production into a system, all else being equal, increases as the size of the wind facility increases. However, this cost is generally a small fraction of the system regulation cost.
- The magnitude of wind integration cost depends on the correlation between the aggregated wind plant output and hourly demand (or spot prices). These results suggest that those examining alternative locations for wind farms should consider costs, prices and revenues as well as local wind speeds.
- Market design can affect the operation and revenues of a wind farm. Penalties should be related to actual system impacts based on detailed analyses.
- It is important that time horizons (gate closure times) for bidding in an electricity market or scheduling power plant be kept to the technically necessary time span, the shorter, the more efficiently can planning be done since in most climates it is usually fairly safe to forecast wind a few hours ahead, whereas it is difficult to forecast accurately several days in advance. In some wind climates (e.g. around the Red Sea, where winds are largely thermally driven) winds are highly predictable even days in advance, whereas in other areas (latitudes around 55-60 degrees with polar fronts moving across the areas), winds may be more difficult to forecast.

**Wind Farm Project Development Documents**
A complete set of project development documents were prepared as part of the Medium Size Project for Developing the Legal and Regulatory Framework for Wind Power in Russia, under a Grant from the International Finance Corporation (IFC) in its capacity as Implementing Agent for the Global Environment Facility (GEF).

These project development documents cover the following aspects of developing a wind farm in significant detail:

- Power Purchase Agreements For Wind Power Plants
- Wind Power Tariffs
- Federal Wholesale Market - Wind Power Sector Participation Process and Agreements
- Legislation For Oblast Financial Incentives For Wind Power Plants
- General Lease Of Land For Wind Power Use
- Model For Obtaining Approvals and Licenses At The Oblast and Federal Levels For Construction and Operation of Wind Power Plants
- Grid Interconnection and Operation For Wind Power Plants

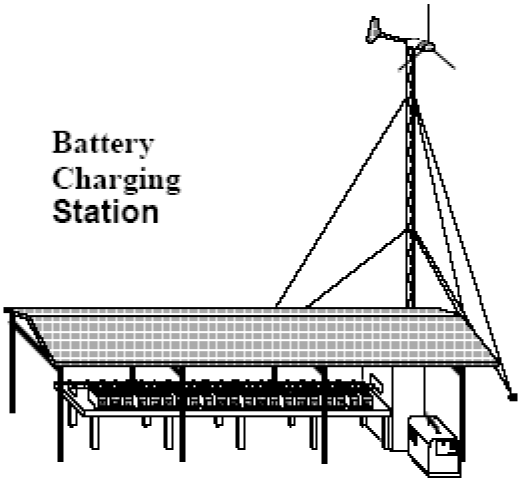
Sample **wind farm bidding documents** are available on the RETToolkit website Technology Module section for Wind technologies.

### Wind Power for Stand Alone Systems

Micro Wind Systems: There are emerging micro-wind systems for stand-alone energy supply, as both wind home systems, PV/wind home systems and battery charging stations. These systems provide basic energy services for lighting, radio, television, and the operation of small appliances to hundreds of thousands of rural households and cottage industries that have no access to electricity grids.

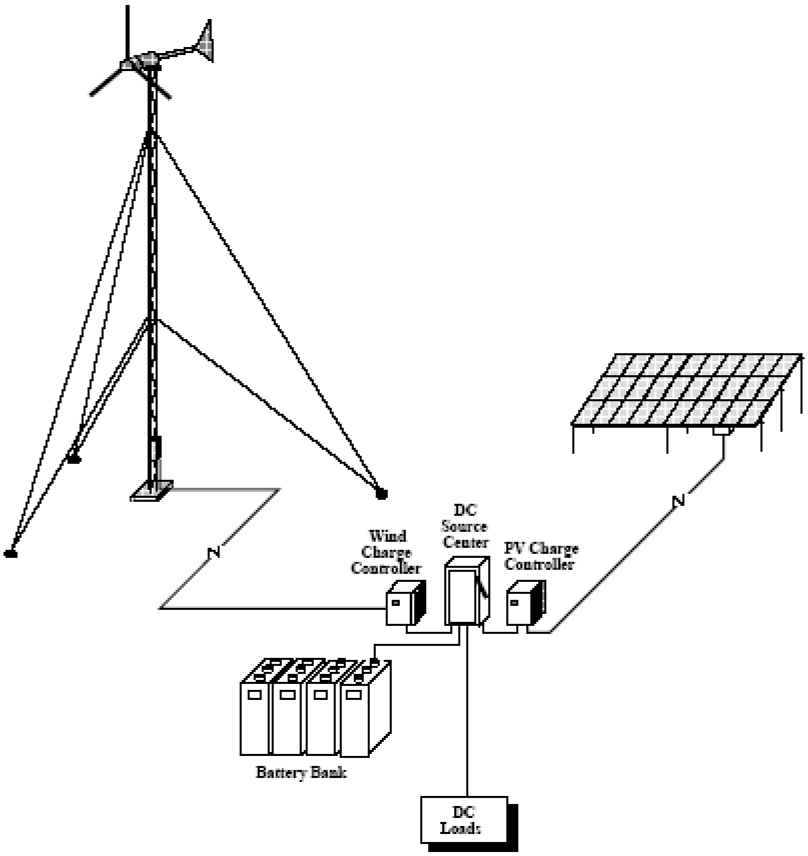
Modern micro-wind turbines are technically sophisticated, high reliability products ranging from a few hundred watts to 50 kW. The turbines generally have only 2 or 3 moving parts and employ passive controls features, which leads to rugged and reliable systems with very low maintenance requirements. Micro-wind systems for water pumping, both mechanical-drive and electric-drive systems, are both proven and commercially available.

There are emerging micro-wind systems for stand-alone energy supply, as both wind home systems, PV/wind home systems and battery charging stations. Household-size wind energy systems have been used most in China, where over 160,000 systems provide energy services for nomadic herdsman in Inner Mongolia. The systems consists of a wind turbine with direct current generator, charge controller, battery, wiring and switches, lights and an outlet. Installed capacity can range from 25 to 100 Watts per household. Wind battery charging stations are a viable option to provide lighting and entertainment services at a more affordable cost than single-household systems. The system consists of a larger wind turbine (often several kW) with a direct current generator, more sophisticated charge controller, battery bank, wiring and switches. Customers bring discharged batteries to the station and return with freshly charged batteries, which they use to power their households lights and appliances. Just like with solar home systems, the customer can replace existing household expenditures for kerosene, candles, and dry-cell batteries with the fees to pay for the charging service.



Wind-PV hybrid systems are used for large stand-alone energy systems, such as schools, clinics and cottage industries, or for mini-grid applications.

The wind and solar resources generally complement each other seasonally and can often provide facility power with no back-up generator. These systems can also supplement or replace portable generators, and if desired, provide AC output from an inverter. Typical size for a school is 1.5 kWp.



## Biomass[13],[14]

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[13] Global Bionergy Partnership (GBEP): Up to date database on global bioenergy information and resources: http://www.globalbioenergy.org/bioenergyinfo.html

Bioenergy Wiki: Online Knowledge Platform for Bioenergy Resources: http://www.bioenergywiki.net/index.php/Main_Page

Biomass energy (or bioenergy) refers to the use of plant and other organic materials to provide energy services such as heat, light and motive power. Biomass is currently the most common form or renewable energy. Even in today's fossil fuel era, bioenergy provides about 11 percent of the world's total primary energy supply, with much larger fractions in most developing countries and some industrialized countries as shown in the table below with data from 2000.[15]

Most of this bioenergy consists of unrefined fuels, such as firewood, charcoal, crop and animal residues. Furthermore, it is used in traditional ways with cheap and simple devices such as cook stoves and earthen kilns, which are polluting and often not sustainable. Most of this biomass is used for essential survival needs such as cooking, space and water heating and crop drying, and it accounts for about one third of all energy in less developed countries as a whole, and as much as 90 percent or more in the poorest countries.

Firewood and agricultural residues used for cooking and heating produce indoor smoke pollution, which leads to respiratory disease. Women & children spend much time gathering and carrying fuel that could be more productively used for education and income generation. Many under-used biomass resources are waste products, such as human & animal manure, garbage, and food processing and other industrial waste.

Much biomass technology development effort has been focused on converting biomass into modern energy carriers, such as electricity, liquid fuels for transportation and gaseous fuels for cooking. Some of these modern forms of bioenergy are inherently more efficient, versatile and convenient.

Table 5.1. Role of Biomass Energy by Major Region in 2000 (EJ/Year)

| Region | World | OECD | Non-OECD | Africa | Latin America | Asia |
|---|---|---|---|---|---|---|
| Primary energy | 423.3 | 222.6 | 200.7 | 20.7 | 18.7 | 93.7 |
| Biomass (%) | 10.8% | 3.4% | 19.1% | 49.5% | 17.6% | 25.1% |
| Modern Bioenergy | 9.8 | 5.2 | 4.6 | 1.0 | 1.9 | 1.5 |
| % of primary energy | 2.3% | 2.3% | 2.3% | 4.7% | 10.0% | 1.6% |
| Modern Bioenergy inputs to: | | | | | | |
| Electricity, CHP & heat plant | 4.12 | 3.72 | 0.39 | 0 | 0.14 | 0.07 |
| % of total sector inputs | 2.7% | 4.1% | 0.6% | 0% | 3.4% | 0.2% |
| Industry | 5.31 | 1.34 | 3.97 | 0.98 | 1.45 | 1.44 |
| % of total sector inputs | 5.8% | 3.0% | 8.6% | 30.3% | 26.0% | 6.3% |
| Transport | 0.35 | 0.10 | 0.26 | 0 | 0.29 | 0.03 |
| % of total sector inputs | 0.5% | 0.2% | 1.1% | 0% | 6.3% | 0.4% |

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[14] Biofuels for Transportation: Extended Summary, June 2006, Worldwatch Institute. http://www.europabio.org/Biofuels%20reports/Worldwatch_biofuels.pdf

[15] Advancing Bioenergy for Sustainable Development: Guidelines for Policymakers and Investors, Volumes I, II, and III, ESMAP Report 300/05, April 2005. http://www.esmap.org/filez/pubs/30005BiomassFinawithcovers.pdf

**Global Status**:

According to the REN 21 2007 Global Status Report[16], an estimated 45 GW of biomass power capacity existed in 2006. Biomass co-firing (burning small portions of biomass in coal-fired power plants) increased in the UK during this year, as did the use of biomass for heating and combined heat-and-power (CHP) in Austria, Denmark, Finland, Sweden and the Baltic countires. The use of bagasse (residues after sugar cane processing) for power and heat in 2006 showd the most significant growth in Asutralia, Brazil, China, Colombia, Cuba, India, the Philippines and Thailand. Europe consumed 6 million tons of biomass pellets in 2005, with about half for residential heating and the remaining half for power generation. With a typical plant size ranging from 1- 20 MW, the energy costs of biomass power were between 5 -12 US cents/kilowatt-hour.

For biofuels, production of fuel ethanol for vehicles reached 39 billion liters in 2006, from increased production mostly in the US (over 18 billion liters) and Brazil (almost 18 billion liters). Biodiesel production increased 50 percent in 2006 over the previous year, to over 6 billion liters globally. Half of the world biodiesel production occurred in Germany with significant production increases in Italy, US and Southeast Asia.

## Resource Assessment

Bioenergy resources take many forms, which can be broadly classified into three categories: residues and wastes, purpose-grown energy crops, and natural vegetation.

Natural vegetation might be a sustainable resource in some situations, but it has not been used sustainably on a large scale. For example, sustainable harvesting of forest growth is possible in theory, but ensuring that ecological and socioeconomic constraints are satisfied is difficult in practice. Therefore, most sustainable bioenergy resources are generally residues from forestry and agriculture, or energy crops.

Bioenergy systems require sufficient, reliable, sustainable, and affordable biomass supplies. These supplies must be grown, harvested, gathered, and transported to the energy conversion plant, sometimes from a large number of dispersed suppliers. They must usually be stored and perhaps dried to avoid deterioration. In many cases the biomass must be chopped, pelletized or otherwise prepared for use as a biofuel. These resource supply activities set bioenergy apart from other renewable resources that are freely available.

While the additional steps in the biomass resource supply chain can bring substantial benefits in the form of local employment and income, they may also raise serious problems which do not apply to other energy resources. In large part, these problems occur because biofuel supply and use is embedded in the production and use of all forms

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[16] REN21. 2008. "Renewables 2007 Global Status Report" (Paris: REN21 Secretariat and Washington, DC:Worldwatch Institute). http://ren21.net/pdf/RE2007_Global_Status_Report.pdf

of biomass, which are in turn embedded in highly complex, dynamic, multipurpose and competitive land use and labor systems that form the bedrock of rural economies.

Critical aspects of these systems vary greatly from place to place and also over time as economic, social and environmental conditions change. Yet these site specific and varying conditions govern to a large extent the amounts and kinds of biomass resources that can be produced, the costs of production and associated benefits such as farm income and rural employment, resulting biomass prices, vulnerability to supply failure, environmental impacts (positive and/or negative), and risks of harming existing biomass dependent social groups.

There are thus rarely any “one size fits all” solutions: bioenergy projects must usually be tailored to the biophysical and socioeconomic circumstances of each location and must be supported by a great variety of stakeholders. These factors must be carefully assessed before each project or program can be successfully implemented.

**Technical Summary***:*

### *Biomass Combustion*

Direct combustion systems burn biomass fuel in a boiler to produce steam that is expanded in a turbine to produce power. Nearly all current biomass power generation is based on direct combustion in small, biomass-only plants with relatively low electric efficiency (20%).

Combined heat and power (CHP) applications involve recovery of heat for steam and/or hot water for district heating, industrial processes, and other applications. Total system efficiencies for CHP can approach 90%.

Co-firing substitutes biomass for coal or other fossil fuels in existing coal-fired boilers. For the near term, co-firing is the most cost-effective of the power-only technologies. Co-firing levels range from 5 to 15% of the normal coal input (on a heat-input basis) and generally require separate feed preparation and injection systems.

Biomass co-firing with coal ($50 - 250/kW of biomass capacity) is the most near-term option for large-scale use of biomass for power-only electricity generation. Co-firing also reduces sulfur dioxide and nitrogen oxide emissions. In addition, when co-firing crop and forest-product residues, GHG emissions are reduced by a greater percentage[17] (e.g. 23% GHG emissions reduction with 15% co-firing).

### *Biomass Gasification*

Biomass gasification produces synthesis gas (syngas), which can be burned in combustion turbines, and allows a high efficiency (> 40%) combined cycle power plants to be used. Other technologies being developed include integrated gasification/fuel cell and bio-refinery concepts.

Biomass gasification for large-scale (20 - 100$MW_e$) power production is an emerging commercial technology. Once fully commercialized, it will be an important technology for cogeneration in the forest-products industries, as well as for new baseload capacity.

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[17] Power Technologies Energy Databook. Edition 4. NREL. March, 2006. http://www.nrel.gov/analysis/power_databook/docs/pdf/db_chapter02_bio.pdf

Small biomass gasification systems have been used for many years in the developing world for electricity generation and industrial process heat. However, these systems have not always been reliable and clean. Recently, biomass gasification systems for village-power applications and for developed-world distributed generation have been developed that are efficient, reliable, and clean and range in size from 3kW to 5MW.

### *Industrial Biogas*

Large-scale agro-industrial processes often produce waste streams with very high organic contents. These waste streams can be converted to a methane-rich gas in an anaerobic digester gas, and that gas can be used to run a combustion turbine or gas engine to make electricity or it can be burned in a boiler for heat. Typical industry sectors with high potential waste streams include combined animal feedlots, sugar mills and molasses distilleries, breweries and food processing industries.

In most countries, this biomass resource is generally small from a national perspective, but it can represent a high-value opportunity in developing countries where the power would be generated in rural areas that currently lack supplies.

### *Landfill Gas*

Landfill gas (LFG) is approximately 50 percent methane and 50 percent carbon dioxide and results from the decomposition of organic waste materials disposed in modern “sanitary” landfills through anaerobic decomposition of the waste.

Most developing country cities still dispose of their municipal solid waste in open dumps creating problems with leachate contamination of surface and groundwater, and the uncontrolled release of LFG to the atmosphere. Because LFG is approximately 50 percent methane, it is a powerful greenhouse gas (21 times more potent than $CO_2$).

The more important and prosperous cities in some developing countries (especially in Latin America) have begun to improve disposal practice and have introduced sanitary landfills[18]. Notwithstanding this trend, only a few cities in developing countries actively collect LFG and utilize its energy value.

The capital cost of LFG collection and utilization infrastructure and the infancy of the carbon and renewable energy markets make the development of these projects most applicable to large and deep landfills (generally greater than 1 million tonnes of waste in place with a depth of more than 15 meters). However, each potential LFG utilization project should be evaluated based on local conditions including the conditions at the landfill, the opportunity to sell carbon credits, the price of energy, available tax credits, and available "green" incentives.

Smaller LFG management projects become more viable as the value of Carbon Emission Reduction units (CER’s)[19] increase and as the value of energy products increase. In

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[18] Handbook for The Preparation of Landfill Gas to Energy Projects in Latin America and the Caribbean, World Bank, ESMAP, January, 2004.
http://imagebank.worldbank.org/servlet/WDSContentServer/IW3P/IB/2005/08/09/000160016_20050809131543/Rendered/PDF/332640handbook.pdf

[19] A Certified Emissions Reduction unit (CER) is equivalent to one metric tone of CO2 reduced or sequestered through a Clean Development Mechanism (CDM) project as defined in Article 12 of the Kyoto Protocol.

Europe, the energy pricing can support projects of less than 0.5 MW and less than 1 million tonnes of waste in place.

### Cost and Performance

More information on the technologies and their cost and performance characteristics can be found the following documents:

- Advancing Bioenergy for Sustainable Development: Guidelines for Policymakers and Investors, ESMAP Report 300/05, April 2005.
- Bioenergy Primer: Modernized Biomass Energy for Sustainable Development, Sivan Kartha and Eric D. Larson, United Nations Development Programme.

### Codes and Standards

Design standards and safety certifications are essential for biomass power generation equipment. Biomass-fueled high-pressure boilers have existed since the beginning of the industrial revolution, and design specifications and safety codes are certifications well-evolved.

Many specific codes and standards exist. In Europe, USA and India, boilers and pressure vessels must comply with respectively the Pressure Equipment Directive (PED), the American Society of Mechanical Engineers (ASME) code and the Indian Boiler Regulation (IBR). The boiler and pressure vessel equipment must be certified by an independent notified body to ensure compliance with all regulations. Reputable manufacturers of biomass-fired boilers will provide certified equipment. Other biomass equipment, such as fluidized-bed or entrained-flow gasifiers may follow sections of these codes, for example sections relevant to material properties for high-temperature service.

Biomass-handling equipment, such as chippers, dryers, conveyors and screw feeders may be designed to other standards. The critical issue from the systems perspective is that all the equipment selected for a power plant should be compatible and well integrated to ensure reliable and safe operation of the plant.

### Grid Interconnection

Power plants using biomass fuels are dispatchable and have operating characteristics (from the perspective of the electricity grid) that are similar to conventional power plants. Therefore, special grid interconnections requirements do not generally need to be considered, as they are in the case of e.g. wind farms.

## Mini Grid Biomass Power Systems

Mini-grid systems that use biomass resources are generally based on modular technologies for either combustion or gasification. For the best performance, the technology specifications and the system design need to be tailored to the characteristics of the biomass feedstock. Direct combustion systems use steam turbines and are generally used for only the larger applications. Modular biomass gasification systems produce a synthesis gas, which can be burned in a gas or diesel engine to provide electricity and motive power and burned in a boiler or furnace to provide heat, are applicable at sizes ranging from a few kilowatts to a few megawatts. As large quantities of solid materials are involved in biomass systems, the system design must accommodate the collection, storage, preparation and processing of the feedstock as well as removal, processing and disposal of ash residues.

Feedstock characteristics that can influence the design and selection of technology and equipment include particle size distribution, moisture content, organic and non-organic (ash) content, chemical composition and energy content. Feedstock preparation steps can often include size reduction and drying, and one of the common design choices how much automation to build into the feedstock handling steps. Industrialized countries with high labor costs tend to build highly automated systems, whereas in developing countries where labor is cheaper, much of the feedstock handling is manual or mechanized, but not automated.

### Biomass combustion for Mini-Grids

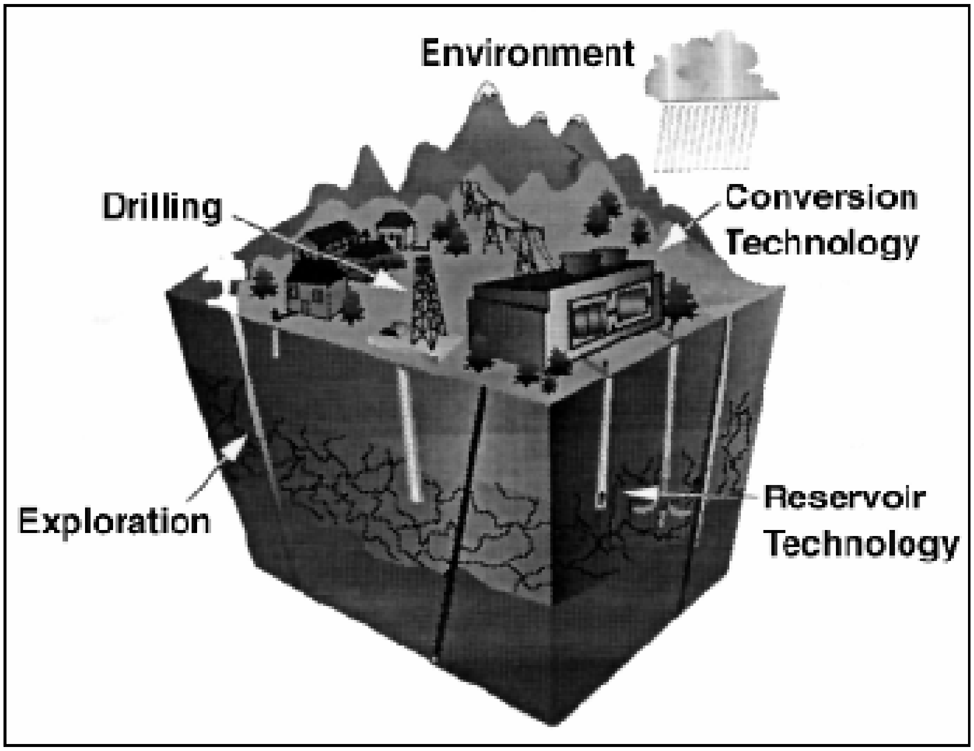
For mini-grid systems, modular technology is preferred, because it offers relatively less expensive systems with higher reliability, because the modules can be pre-assembled in a factory and tested before shipping to a remote village site. The main drawback of steam-turbine based systems is the relatively high operating pressures and the level of technical skills required for plant operation. Thus, they tend to be used only for applications greater than a few MWs.

Where heat or cooling is a need, either in cold or warm climates or for small industry use, combined heat and power (CHP) applications can be cost-effective. Total system efficiencies for CHP can approach 90%.

## Geothermal

Geothermal energy is thermal energy from within the Earth that takes the form of hot water and steam. When brought to the surface, these can be used to produce electricity or applied directly for space heating and industrial processes.

Geothermal power plant development involves geophysical, geochemical, and geological exploration to locate permeable hot reservoirs to drill. The drilling of wells into these reservoirs is the largest project development cost and entails significant risk, as the resource may not be are large or well located as indicated by the exploration activities. Once the geothermal resource is properly tapped, well fields and distribution systems allow the hot geothermal fluids to move to the power generation block, which consists of either steam turbines using natural steam, hot water flashed to steam, or binary turbines using an organic working fluid. Once passed through the power conversion system, the geothermal fluid is injected back to the earth.



**Global Status**[20]

In 2006, geothermal energy provided almost 10 GW of power, growing at 2-3 percent per year over the previous years. Most of this use occurred in Italy, Indonesia, Japan, Mexico, New Zealand, Philippines and the United States. Iceland derived one-quarter of all its power as well as 85% of its total space-heating needs from geothermal resources . Over 2 million ground-source heat pumps were in use worldwide in 2006.

**Resource Requirements**

The US Geothermal Education Office maintains a database of geothermal resources around the world, and the US Department of Energy maintains a database and maps of geothermal resources in the US. For more information go to:

- Geothermal Education Office:
- US Department of Energy - Geothermal Technology Office:

*Technology Descriptions*

Representative technologies include the following.

- Dry-steam plants, which use geothermal steam to spin turbines.

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[20] REN21. 2008. "Renewables 2007 Global Status Report" (Paris: REN21 Secretariat and Washington, DC:Worldwatch Institute). For most up to date renewable energy global status information, please visit REN21 to access the most recent Global Status Report.

- Flash-steam plants, which pump deep, high-pressure hot water into lower-pressure tanks and use the resulting, flashed steam to drive turbines.
- Binary-cycle plants, which use moderately hot geothermal water to heat a secondary fluid with a much lower boiling point than water. This causes the secondary fluid to flash to vapor, which then drives the turbines.
- A developmental technology called Hot Dry Rocks involves the identification, drilling and fracturing of hot dry geothermal reservoirs. Water is then pumped through the fractures to access the resource. This technology is not yet commercially developed.

## Solar

Sunlight can be converted by a variety of technologies into heat and electricity. Grid-connected solar technologies consist of solar thermal concentrating systems and photovoltaic (PV) systems. In the US, Approximately 500 MW of solar (thermal) trough power plants were built in the 1980s and are still operating in the state of California. New solar trough power plants are currently under construction in, Egypt, Morocco and Mexico.

Solar home systems (SHS) currently provide basic energy services for lighting, radio, television, and the operation of small appliances to millions of rural households and cottage industries that have no access to electricity grids. A typical solar home system includes a 10- to 100-Wp (peak watts) photovoltaic array; a rechargeable battery for energy storage; a battery charge controller; one or more lights (generally fluorescent or LED); an outlet for a television, radio/cassette/CD/DVD player, or other low-power-consuming appliances; and switches, interconnecting wires, and mounting hardware (See figure 5.4). Portable solar lanterns are also gaining in popularity, particularly in India where the government has promoted its use since the mid-1980s. Both the module size and the sunlight availability will determine the amount of electricity available for daily use. In a country such as Indonesia, a 50-Wp system can provide enough energy to operate four small (6- to 10-W) fluorescent lights and a small 15-inch black-and-white television for up to five hours.. The retail price of a SHS ranges from about US$100 to US$500 for 10 Wp to 50 Wp systems, respectively.[21] The smaller and cheaper systems are tailored for low-income consumers and for cash-sales. The larger systems require additional financing.

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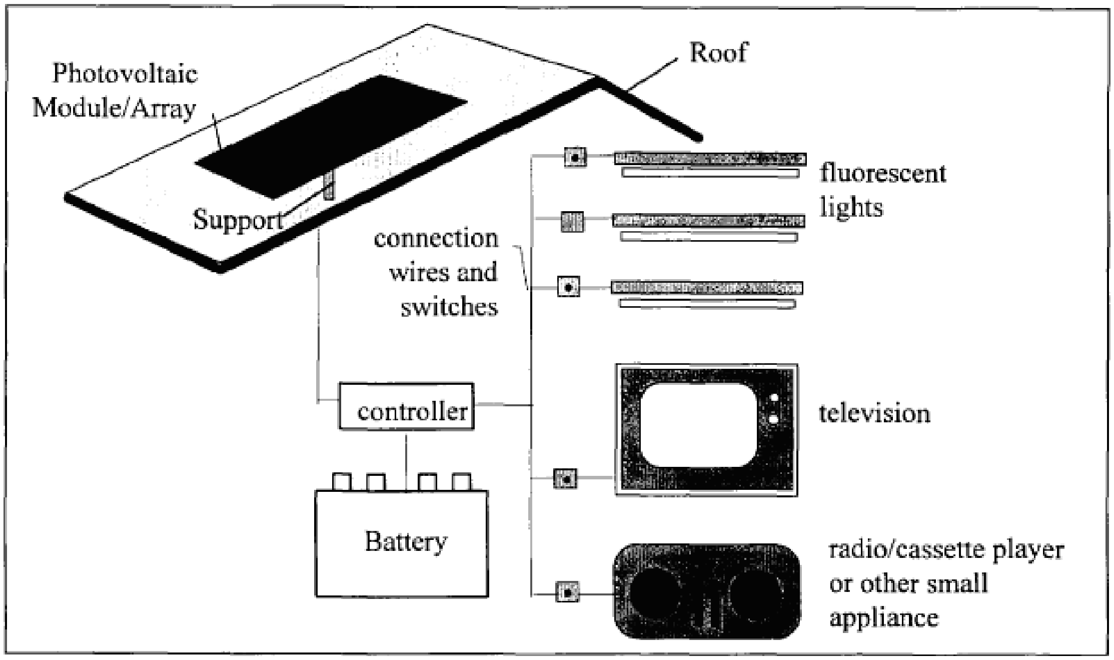
[21] World Bank Solar Home Systems Projects: Experiences and Lessons Learnt 1993-2000. Eric Martinot and Anil Cabraal *Renewable Energy*, proceedings of the World Renewable Energy Congress VI, Brighton, UK, A.A.M. Sayigh, ed.(Elsevier Science, Oxford, UK, 2000) www.martinot.info/Martinot_Cabraal_WREC2000.pdf

**Figure 5.4. Typical System Components of Stand Alone Solar Systems.**



## Global Status

At the end of 2007, cumulative existing solar PV worldwide reached 10.5 GW, up from 7.7 GW in 2006[22]. The majority of these installations are in grid-connected applications. In the industrial nations, these applications have been driven by strong incentives and high retail electricity tariffs. In Germany, Spain, USA and Japan for example, government incentives have driven the growth in capacity of local manufacturing industries as a strategy to lower system costs and gain market share.

## System cost and performance:

The costs to consumers for solar home systems vary significantly by country and depend on a number of factors, such as sales volumes, dealer margins, maturity of local manufacturing and marketing infrastructure, duties and taxes, level of competition, etc. Indonesia and China have some of the lowest systems costs because of low duties and taxes, high sales volumes and low manufacturing costs. Typical costs for systems in China are shown in Table 5.2 below.[23]

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[22] REN21. 2008. "Renewables 2007 Global Status Report" (Paris: REN21 Secretariat and Washington, DC:Worldwatch Institute). For most up to date renewable energy global status information, please visit REN21 to access the most recent Global Status Report.

[23] Project Management Office, "Market Price Research On China SHS," China Renewable Energy Development Project, March 2008

**Table 5.2. The factory (retail) price of PV sytems in the first half of 2007**

| System Specification | | Sample | Maximum ($/Set) | Minimum ($/Set) | Average Value ($/Set) |
|---|---|---|---|---|---|
| *System Power(W)* | *Storage Battery Capacity(Ah)* | | | | |
| 10 | 17 | 21 | 212.3 | 60 | 90.71 |
| 18 | 25 | 17 | 228.6 | 85.7 | 134.43 |
| 20 | 40 | 19 | 331.1 | 98.6 | 168.29 |
| 40 | 40 | 15 | 534.7 | 167.1 | 266 |
| 50 | 80 | 16 | 694.1 | 231.4 | 425.14 |

Costs in other countries may be significantly higher due to a combination of high duties and taxes and high dealer margins, as shown from a few samples:

**PV Systems Retail Price Comparisons**

| | Philippines | Indonesia | Sri Lanka | India | Kenya |
|---|---|---|---|---|---|
| 20 Wp System | 300 | | 302 | | |
| 37 Wp System | | | | 270 | |
| 40Wp System | 520 | 303 | 419 | 307 | |
| 50Wp System | 660 | 300-408 | 480 | 360 | 822 |
| 75-80 Wp | 750-1000 | | 686 | | |

Sri Lanka 3 lights (20Wp), 4 lights (40Wp), 6 lights (50Wp), 10 lights (80Wp); India 37Wp has 2 lights and 2-year full service; others include 3 lights

Philippines units costs are estimated by AED (Ph) Ltd. 75 Wp range: AED (750) and sales price of one dealer ($1000, includes inverter)

Prices include duties and taxes

## Hybrid Power Systems

While diesel generation has the largest share of the existing non-grid market for power generation, it is often not featured in donor projects. This is due to the fact that (i) ongoing fuel subsidies for existing remote diesel systems place a heavy burden on public budgets in many client countries and (ii) renewable energy-based alternatives are mostly environmentally benign and therefore less critical regarding environmental safeguards. However, it is possible retrofit existing diesel supply with RE and/or battery add-ons. This is a potentially giant market, and important both for increasing energy access and for mitigation and adaptation of the climate change. Incentives for improving the efficiency of existing diesel systems (e.g. via better load management or retrofitting with hybrid renewable add-ons and/or battery storage) and for implementing innovative RE-diesel-hybrid-solutions in green field projects should be included in all electrification subsidy programs regulatory frameworks[24]. Hybrid systems, such as solar/diesel, wind/diesel and solar/wind have their roots in telecommunications applications for remote sites.

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[24] Promoting Electrification: Regulatory Principles and a Model Law. Kilian Reich, Bernard Tenenbaum and Clemencia Torres. ESMAP, November, 2005.

However, properly optimized hybrid systems can substantially reduce diesel fuel consumption while increasing system reliability.

While wind, PV, and micro-hydro have been commercial technologies for a number of years, their hybridization with fossil fuel generator sets for rural applications are an emerging technology. Such hybrid systems combining renewable energy and fossil energy components have their roots in telecommunications applications in remote sites. However, the extremely high-value electricity for telecommunication applications results in expensive, extreme reliability designs that are inappropriate for rural electricity service. Furthermore, the village hybrid market is at a very early stage of development, and the design, manufacturing, integration, implementation, and distribution segments of the industry are sparse and immature.

### ***Technical Summary***

There are a large variety of possible hybrid power systems, but the most common types include:

- PV-Diesel hybrids
- Wind-PV-Diesel hybrids
- Wind-Diesel hybrids
- Retrofit systems

These systems can be developed a retrofits of existing diesel mini-grid systems or as new integrated designs. NREL has developed a series of pilot village power systems that have exemplified these system types. Other developers that are active in this area include Trama TecnoAmbiental, The Fraunhofer Institute for Solar Energy Systems, and ISET (Institut für Solare Energieversorgungstechnik).

In general, well designed hybrid systems will substantially reduce diesel fuel consumption while increasing system reliability. In addition to the diesel generator and the renewable energy generator, hybrid systems consist of a battery bank for energy storage, a control system and particular system architecture that allows optimal use of all components.

The diesel fuel savings of hybrid systems are associated with a control strategy and system architecture that allows shutting down the diesel generator when the renewable energy system output is sufficient to carry the load, and uses short-term battery storage to reduce diesel generator start-ups. In northern climates, an added feature is using both waste diesel heat and surplus renewable energy to supply space heating to community buildings.

Experience from several of the NREL pilot systems indicates that in many cases hybrid system:

- Provided power at lower costs than grid extension
- Were more reliable than grid power,
- Provided much higher service levels than diesel-only systems
- Were very modular and could be assembled from standardized packages
- Were relatively easy to fully automate

### *Cost, Performance and Project Risks*

Hybrid systems are potentially very cost-effective solutions to rural AC electricity needs. For low load applications (< 10 kWh/day), Wind/PV Hybrid Systems are very attractive. For Larger Applications, Wind/Diesel Hybrids are very attractive as long as a reasonable wind resource is available. Bilateral and multilateral finance and market stimulation programs should be based on best service at least cost.

The cost of hybrid systems is currently high compared to conventional diesel mini-grid systems. However, as is typical of emerging technologies/markets, systems design and industry structure will continue to evolve in concert with the growth in demand and technology development funding, and costs can be expected to decrease dramatically.

Wind and solar energy components and Diesels have complimentary technology characteristics, as shown in the table below. Together, they provide a more reliable and cost-effective power system than is possible with either wind, solar or diesel alone.

| **Characteristic** | **Wind/Solar** | **Diesel** |
|---|---|---|
| Capital Cost | High | Low |
| Operating Cost | Low | High |
| Logistics Burden | Low | High |
| Maintenance Requirements | Low | High |
| Available On-Demand | No | Yes |

## Capital cost comparison[25]

The World Bank funded Technical and Economic Assessment of Offgrid, Mini-Grid and Grid Electrification Technologies[26] developed capital cost estimates in (US$/kW) for 22 renewable and conventional electricity generating technologies. The objective was to identify, characterize and assess the technical, economic and commercial prospects for electricity generation and delivery technologies to serve rural, peri-urban and urban populations in developing countries. The study revealed that:

- Renewable energy is more economical than conventional generation for off-grid (less than 5 kW) applications.

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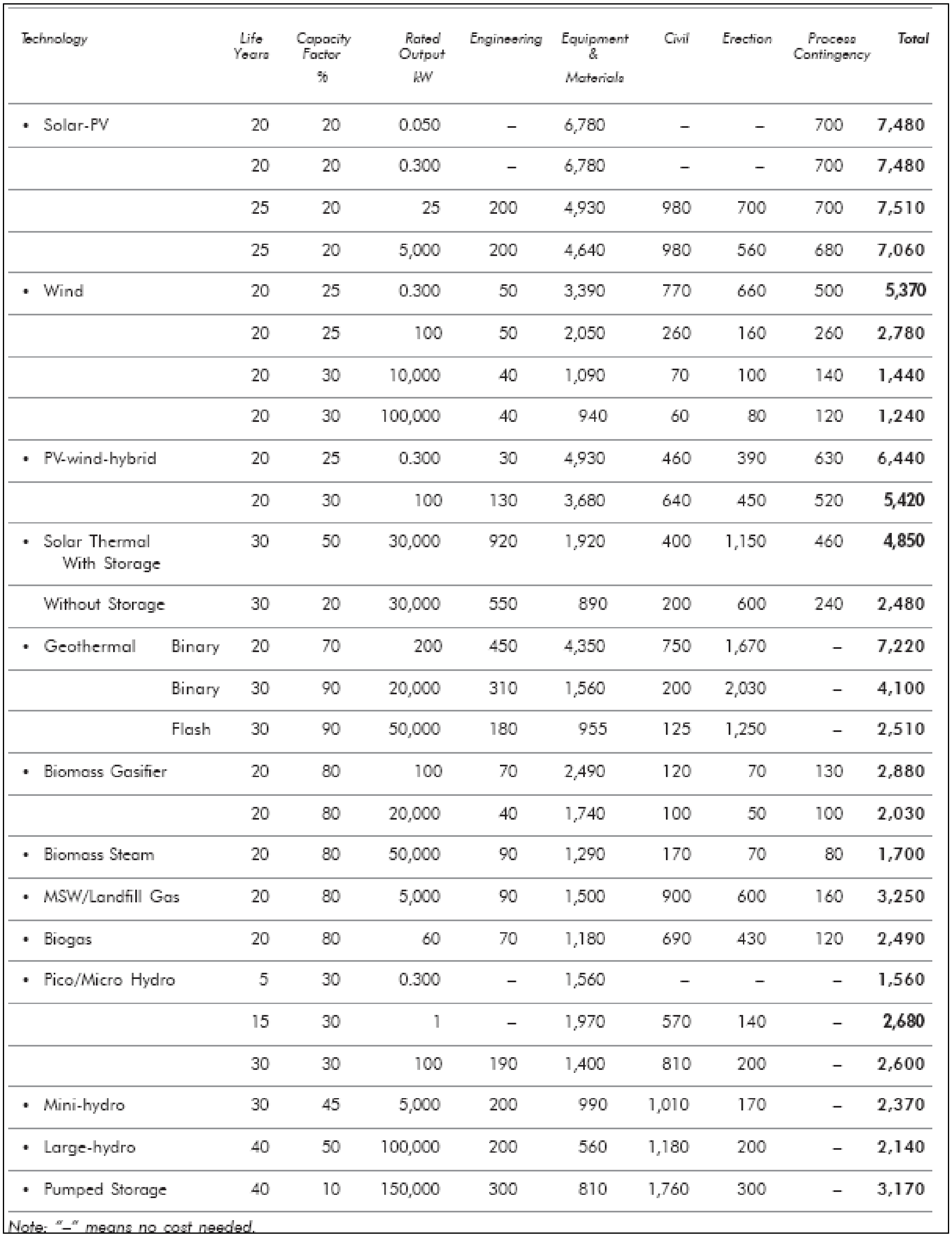
[25] As mentioned at the beginning of this chapter, this study is presently outdated, since costs in the power generation sector have grown considerably during the period 2006-2008 and the charts provided here are merely an illustration to show the relative economics in 2005-2006. The World bank ESMAP unit is currently (May 2008) conducting a new study, which will be referenced in a future edition of this publication.

[26] Technical and Economic Assessment of Off-grid, Mini-grid and Grid Electrification Technologies. ESMAP Technical Paper 121/07, December 2007. http://siteresources.worldbank.org/EXTENERGY/Resources/336805-1157034157861/ElectrificationAssessmentRptSummaryFINAL17May07.pdf

- Several renewable energy technologies are potentially the least-cost mini-grid generation technology.
- Conventional power generation technologies remain more economical for most large grid connected applications, even with increases in oil price forecasts.
- Integrated Gasification Combined Cycle (IGCC) and Atmospheric Fluidized Bed Combustion (AFBC) have considerable potential for developing economies.

As an illustration of the analyses performed in the report, the renewable energy capital cost estimates from this study are replicated in Table 5.3 which includes equipment costs, civil costs, installation costs and contingency. The capital and fuel costs have increased significantly since the study and the data presented here is an illustration of the relative cost structures in 2005. Further details and analyses are available in the 2007 ESMAP report of this study: Technical and Economic Assessment of Off-grid, Mini-grid and Grid Electrification Technologies

Table 5.3. Renewable Power Technology Capital Costs in 2005 (US$/kW)



| Technology | | Life Years | Capacity Factor % | Rated Output kW | Engineering | Equipment & Materials | Civil | Erection | Process Contingency | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| • Solar-PV | | 20 | 20 | 0.050 | – | 6,780 | – | – | 700 | **7,480** |
| | | 20 | 20 | 0.300 | – | 6,780 | – | – | 700 | **7,480** |
| | | 25 | 20 | 25 | 200 | 4,930 | 980 | 700 | 700 | **7,510** |
| | | 25 | 20 | 5,000 | 200 | 4,640 | 980 | 560 | 680 | **7,060** |
| • Wind | | 20 | 25 | 0.300 | 50 | 3,390 | 770 | 660 | 500 | **5,370** |
| | | 20 | 25 | 100 | 50 | 2,050 | 260 | 160 | 260 | **2,780** |
| | | 20 | 30 | 10,000 | 40 | 1,090 | 70 | 100 | 140 | **1,440** |
| | | 20 | 30 | 100,000 | 40 | 940 | 60 | 80 | 120 | **1,240** |
| • PV-wind-hybrid | | 20 | 25 | 0.300 | 30 | 4,930 | 460 | 390 | 630 | **6,440** |
| | | 20 | 30 | 100 | 130 | 3,680 | 640 | 450 | 520 | **5,420** |
| • Solar Thermal<br>With Storage | | 30 | 50 | 30,000 | 920 | 1,920 | 400 | 1,150 | 460 | **4,850** |
| Without Storage | | 30 | 20 | 30,000 | 550 | 890 | 200 | 600 | 240 | **2,480** |
| • Geothermal | Binary | 20 | 70 | 200 | 450 | 4,350 | 750 | 1,670 | – | **7,220** |
| | Binary | 30 | 90 | 20,000 | 310 | 1,560 | 200 | 2,030 | – | **4,100** |
| | Flash | 30 | 90 | 50,000 | 180 | 955 | 125 | 1,250 | – | **2,510** |
| • Biomass Gasifier | | 20 | 80 | 100 | 70 | 2,490 | 120 | 70 | 130 | **2,880** |
| | | 20 | 80 | 20,000 | 40 | 1,740 | 100 | 50 | 100 | **2,030** |
| • Biomass Steam | | 20 | 80 | 50,000 | 90 | 1,290 | 170 | 70 | 80 | **1,700** |
| • MSW/Landfill Gas | | 20 | 80 | 5,000 | 90 | 1,500 | 900 | 600 | 160 | **3,250** |
| • Biogas | | 20 | 80 | 60 | 70 | 1,180 | 690 | 430 | 120 | **2,490** |
| • Pico/Micro Hydro | | 5 | 30 | 0.300 | – | 1,560 | – | – | – | **1,560** |
| | | 15 | 30 | 1 | – | 1,970 | 570 | 140 | – | **2,680** |
| | | 30 | 30 | 100 | 190 | 1,400 | 810 | 200 | – | **2,600** |
| • Mini-hydro | | 30 | 45 | 5,000 | 200 | 990 | 1,010 | 170 | – | **2,370** |
| • Large-hydro | | 40 | 50 | 100,000 | 200 | 560 | 1,180 | 200 | – | **2,140** |
| • Pumped Storage | | 40 | 10 | 150,000 | 300 | 810 | 1,760 | 300 | – | **3,170** |

*Note: "–" means no cost needed.*