Chapter 2
Power Infrastructural Development

Oxford Dictionaries (2013) define infrastructure as the "basic physical and organizational structures and facilities (e.g. buildings, roads, power supplies) needed for the operation of a society or enterprise". Infrastructural development is the foundation upon which any society builds a viable economic engine. Nations that neglect their infrastructure sow the seed of misery, inequity, pervasive poverty, and grand economic failure.

For our purpose, infrastructure includes all the physical systems required to have effective electrical power supply, communications, water supply, transportation (land, water and air), and waste management system. The existence, scale and condition of critical infrastructure in a given society are important development indices.

This chapter, the longest in this book, is devoted solely to the power infrastructure because of the critical role of power[1] in sustainable development. No meaningful economic development will occur in any society that lacks a reliable electrical power supply system. Power is essential for all the key infrastructural development projects highlighted in this book. The other components of infrastructure are presented in Chap. 3.

[1] The words "power" and "energy" are referred to frequently in this section. Power is the rate at which energy is utilized. "Energy" can be likened to the "volume" or "quantity" of water stored in a water tank. Water can be discharged through an orifice or a small opening at the base of the tank. The "rate of discharge" of the water through the orifice is analogous to "power". The higher the discharge rate, the higher the "power" and the faster the quantity of water stored (that is "energy") will be depleted. Electrical power is measured in "watts" while electrical energy is measured in "watt-hours". A 60-watt (60 W) light bulb will consume in one hour $60 \times 1 = 60$ watt-hour (W h) of energy. One kilowatt (1 KW) is the same as 1,000 W. One megawatt (1 MW) is equal to 1,000,000 W. One megawatt hour (1 MW h) is the energy used in one hour by a 1 MW power rated electrical load such as the combined demand of the electrical appliances in a small community or a factory.

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2.1 Power: Index of Economic Development

The per capita 2005 energy consumption by regions of the world is shown on Fig. 2.1. Africa is at the bottom of the list.

A 2009 per capita energy consumption map is shown in Fig. 2.2. The high correlation between energy consumption and economic development is self-evident from the map.

In order to move forward economically, a nation must develop a sustainable electrical power infrastructure. A good electrical power system will have:

(a) an adequate generation capacity;
(b) a manageable and reliable transmission grid;
(c) a robust and effective distribution network.

In some under developed countries of the world industries can spend up to 60 % of their operating costs on self-generation of electricity. That is one key pointer to the failure of manufacturing in many of these countries.

2.1.1 Usage of World's Energy Resources

Coal remains by far the most widely used source of electricity production around the world as shown on the IEA/OECD 2008 (Fig. 2.3). Out of the total balance of energy usage in 2008, 67 % came from fossil fuels, 18 % from renewable energy sources and 13 % was generated by nuclear power plants. The majority of fossil fuel usage for the generation of electricity was of coal and gas. Oil was only 5.5 %. Ninety-two

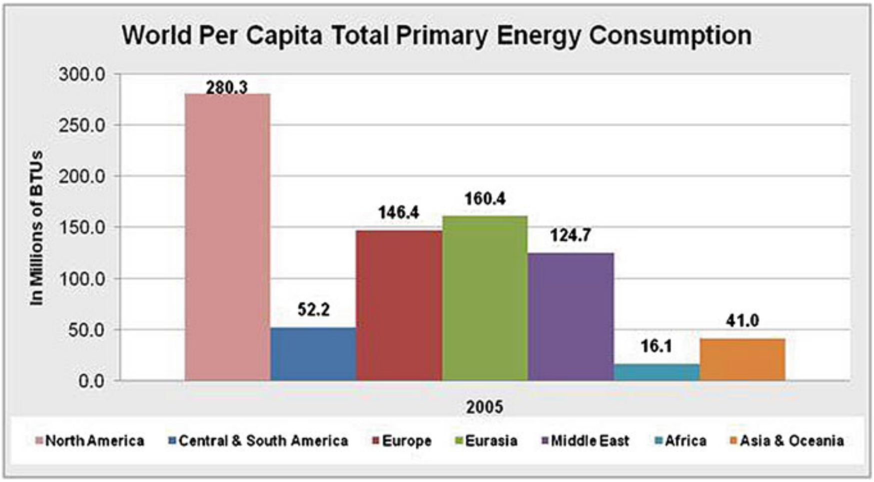

Fig. 2.1 2005 Energy consumption by region per capita. *Source* US Census Bureau

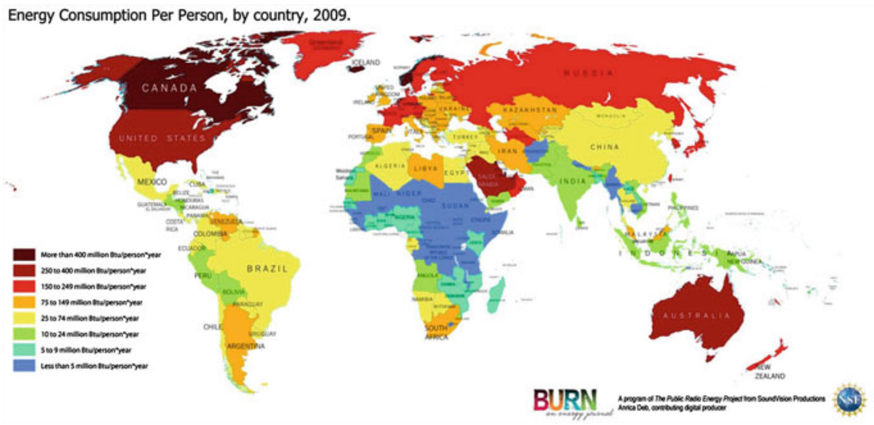

Fig. 2.2 Per capita energy (2009) consumption by countries. *Source* http://burnanenergyjournal.com/wp-content/uploads/2011/12/WorldMap_EnergyConsumptionPerCapita_v4forweb.jpg . Accessed February 2013

Source of Electricity (World total year 2008)							
-	Coal	Oil	Natural Gas	Nuclear	Hydro	Other	Total
Electricity (TWh/year)	8,263	1,111	4,301	2,731	3,288	568	20,261
Proportion	41%	5%	21%	13%	16%	3%	100%

Fig. 2.3 World electricity supply. *Source* IEA/OECD 2008

percent of renewable energy was hydroelectric followed by wind at 6 % and geothermal at 1.8 %. Solar photovoltaic was 0.06 %, and solar thermal was 0.004 %. Renewable energy sources are clearly underutilized in the world today.

2.2 Clean Power, Renewable Energy Sources and Abulecentrism

One of the principal advantages of renewable energy systems over the conventional alternatives is the ease with which power can be generated close to where it is used. This greatly reduces the scale of the supporting transmission and distribution network. Capital costs are thereby lowered and maintenance rigor is reduced.

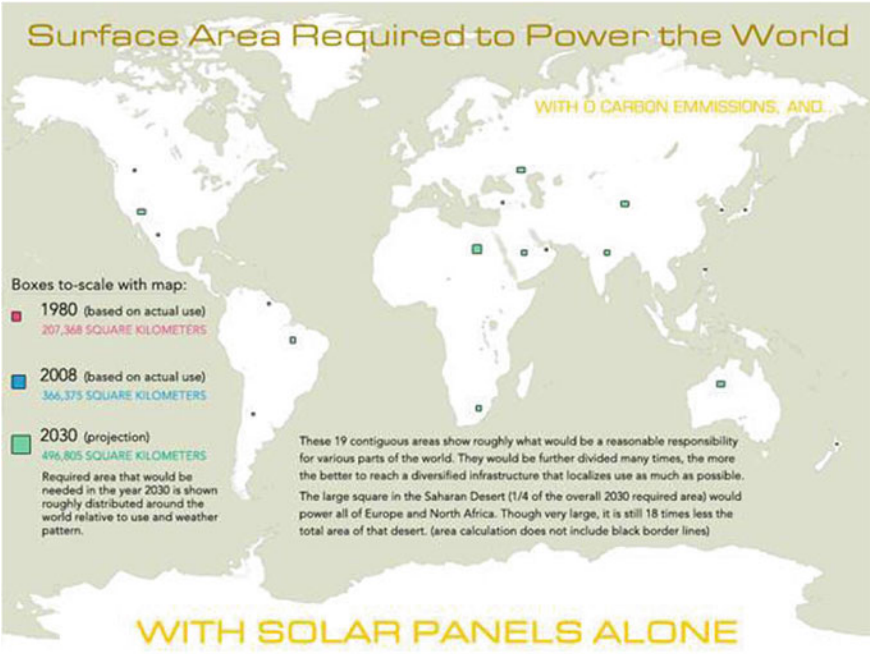

Fig. 2.4 Surface area required to provide electrical power to the whole world with solar panels alone. *Source* http://www.richhesslersolar.com/solar-articles/solar-panels-power-world/. Accessed January 2013

Renewable energy sources are abundant around the world. It is noteworthy that the entire (20,261 T W h) global world production of electricity in 2008 was just 11 % of the solar energy the earth receives in one hour (174,000 T W h). Rich Hessler[2] presented an exciting analysis of the abundance of solar and wind resources and the possibility of meeting all the world's (present and future) energy needs using either of these resources. He wrote:

> The world current consumes 500 quadrillion Btu of energy from all available forms of energy. This number will increase to at least 678 quadrillion Btu over the next 20 years. Since we will not have this scale of energy available in fossil fuels forever, and renewables are the obvious replacement, it is interesting to begin to image what the surface of the earth will look like (Fig. 2.4).
>
> Using only solar panels, we need 191,817 miles^2, or about the area of Spain, to power the whole world using only solar panels. That is a lot of solar panels, but take into consideration the highway system in the United States. It measures approximately 38,000 miles^2. If this was converted into solar panels, the United States would produce enough electricity from solar panels to power itself. 38,000 miles^2 of road has been laid over the past 35 years, so photovoltaic can easily be installed in a reasonable amount of time. If the

[2] *Source* http://www.richhesslersolar.com/solar-articles/solar-panels-power-world/. Accessed January 2013.

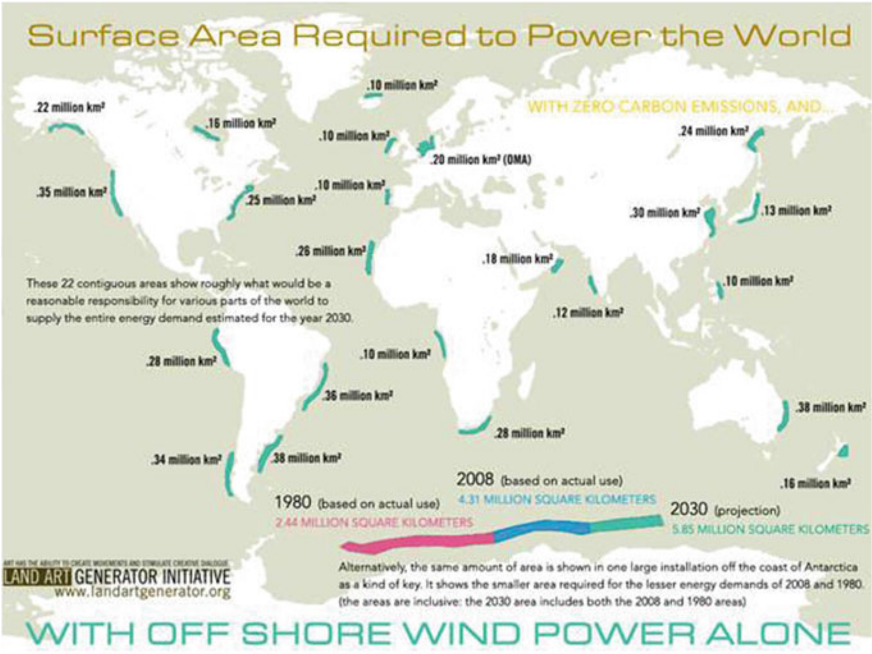

Fig. 2.5 Surface area required to provide electrical power to the whole world with off shore wind turbines alone. *Source* http://www.richhesslersolar.com/solar-articles/solar-panels-power-world/. Accessed January 2013

world was to install enough solar panels to generate all its electricity in 2030, this is what the world might look like.

Another possibility is to power the entire world using off-shore winds. To generate enough electricity from wind, the world might look like this (Fig. 2.5).

To power the world with wind would require 11.7 million 5 MW windmills. Compared to the 500 million cars in the world, this does not seem like a difficult feat.

In reality, electricity will be generated by a combination of wind, solar, hydropower, waves, tidal, geothermal, and biofuels. With current research and development, the price of renewable energy is falling fast. The need to begin installing renewable energy will become more evident as energy prices begin to climb after the end of the worldwide recession. This is where we will see the movement to renewable energy economies and increased profitability of countries set up to harness natural energy.

In a country like Nigeria, the total power target of 40,000 MW (or 40 GW) can be met by covering just 0.03 % of the land area (over 90 M ha) with photovoltaic panels manufactured using current off-the-shelf technologies. There is a profound economic incentive for all developing countries to aggressively embrace renewable energy systems.

Abulecentrism favors renewable power generation for a number of reasons:

1. Renewable energy sources (e.g., solar, wind, hydro, geo-thermal, bio-mass, bio-fuels, ocean waves, tidal waves etc.) are available and often abundant in most local communities in one form or the other.

2. Transmission and distribution can easily be localized to the community since the power is generated within the vicinity.
3. Local or indigenous human capacity in renewable energy conversion technologies is readily developed.
4. Renewable energy systems are easily scaled to the demands of the community.
5. Renewable power generation is pollution-free thereby producing a cleaner environment (Fig. 2.6).

Renewable energy continues to increase every year as a percentage of the total energy world production as shown in Figs. 2.7 and 2.8. That is good.

2.3 Select Renewable Energy Sources

We describe four renewable energy sources (i.e., solar, wind, hydro and biomass) for which excellent conversion technologies have been developed for electrical power supply. At least one of these sources will typically be available in an amount sufficient for power generation in any part of the world.

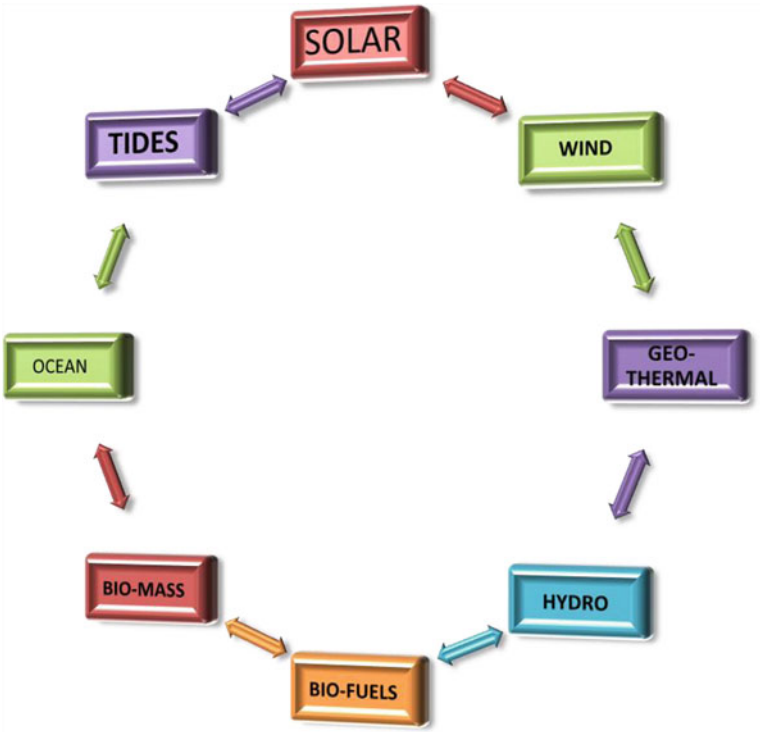

Fig. 2.6 Renewable energy sources. Every location on earth has at least one of these sources in sufficient amount to provide electrical power for the local community

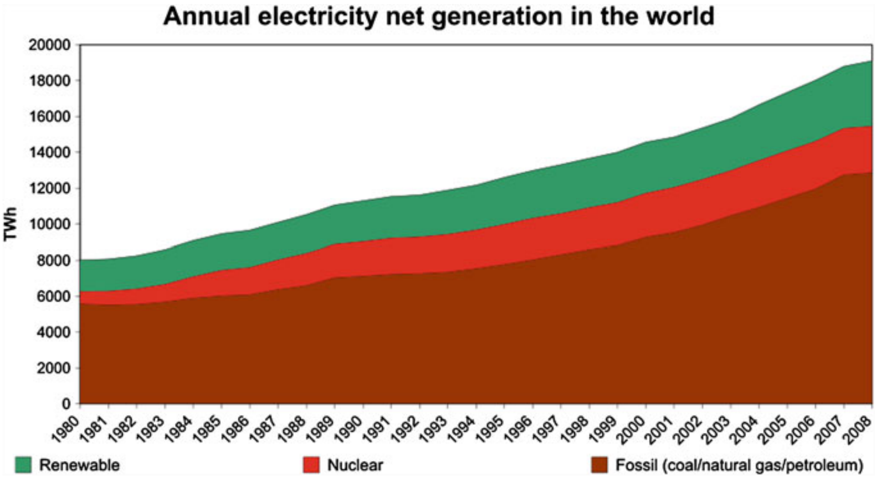

Fig. 2.7 Annual net electricity generation in the world. *Source* International Energy Agency

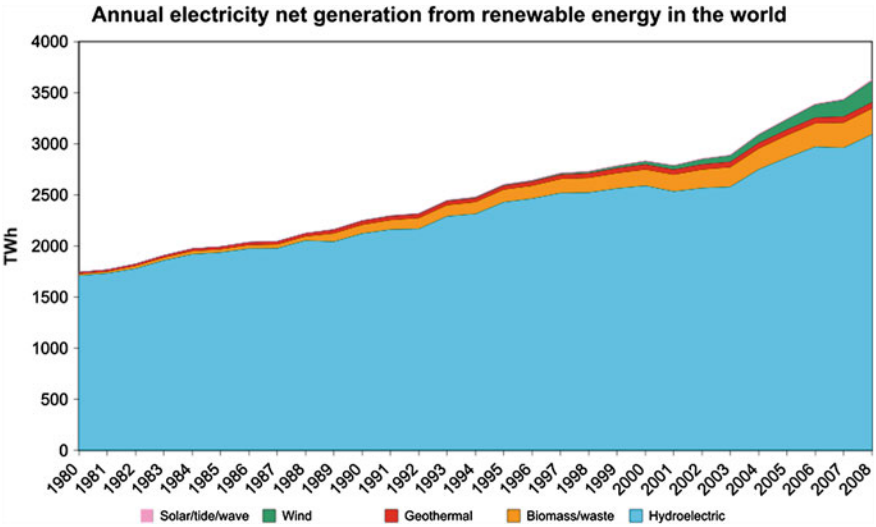

Fig. 2.8 Annual net electricity generation from renewable energy in the world. *Source* International Energy Agency

2.3.1 Solar

The global map of solar radiation distribution is shown in Fig. 2.9. The amount of power received by the earth from the sun is 174,000,000,000,000,000 W or 174 Peta Watts. This power hits the upper earth's atmosphere in the form of solar radiation. About 30 % of the radiation is reflected back to space.

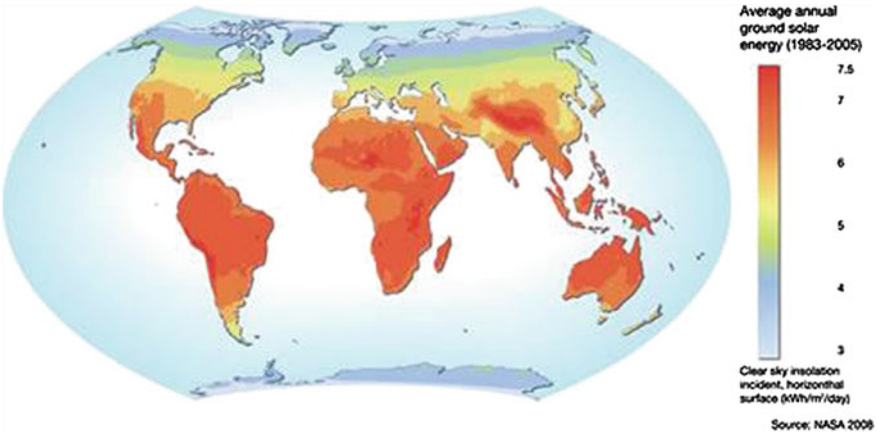

Fig. 2.9 Average annual ground solar energy from 1983–2005. *Source* NASA 2008

The earth's land surface, the oceans and the clouds absorb the balance. The energy produced in one hour by the absorbed radiation is more than sufficient to supply the entire world's annual energy needs.

That energy can be harnessed in the form of light and heat. Special materials and appliances are used to convert the solar energy into forms suitable for practical applications.

2.3.1.1 Photovoltaics

Photovoltaic[3] panels are appliances that convert solar light into electricity. The measure of solar radiation received on a surface area in a given time is known as insolation[4] (Fig. 2.10).

About 1,000 W of the sun's power reaches a square meter of the earth's surface which is perpendicular to the sun's ray on a clear day at sea level. A square meter of a photovoltaic panel with 15 % conversion efficiency will generate 150 W of power when installed on that surface. A huge amount of power (running into several megawatts) can be produced by installing a farm of photovoltaic solar panels (Fig. 2.11).

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[3] The creation of electric current when a material is exposed to light is known as a photovoltaic effect. The phenomenon was first observed by the French Physicist Alexandre-Edmond Becquerel in 1839. The word "photovoltaic" is an amalgamation of part of the word "photons" (the Greek for light) and the surname of the Italian Physicist Allesandro Volta after whom the electric potential (or voltage) measurement quantity "volt" was named. Photovoltaic implies the conversion of sunlight into electricity by use of solar cells.

[4] Insolation is expressed as an average irradiance in watts per square meter or kilowatt-hours per square meter per day. The name comes from the combination of the words **in**cident **sol**ar radi**ation**.

Fig. 2.10 A photovoltaic solar panel

2.3.1.2 Solar Water Heaters

Solar water heaters use the heat from the absorbed solar radiation to produce hot water for buildings and other uses. Figure 2.12 is a schematic of how solar water heating works. Water at normal temperature is pumped through a pipe network (shown in blue) into solar water heater.

The water is moved through a network of tubes that cause the water to be heated either directly by solar radiation or indirectly through a working fluid that has absorbed solar heat. The hot water is then stored in a storage tank from which distribution is made to the entire building. Figure 2.13 shows solar water heating panels installed on the roof of a building.

2.3.1.3 Concentrated Solar Power

Solar concentrators use solar heat to generate steam that power steam turbines. Alternatively, the heat can be stored in a molten salt for later use. Figure 2.14 is the schematic for the parabolic concentrated solar power technology by SkyFuel, Inc. a company based in Colorado (USA).

Figure 2.15 is the picture of a concentrated solar power generator that uses a parabolic dish Stirling engine. In a dish engine, the receiver is placed at the focal point of the parabolic reflector. The working fluid inside the receiver is heated to high temperatures (reaching hundreds of degrees Celsius). The heated working fluid is then used to drive a special engine (Stirling Engine) that converts heat into electricity.

Figure 2.16 is a large scale installation of a farm of reflectors that concentrate the heat to a spot at which steam is generated for the electrical power production from steam turbines. Such installations generate several megawatts of electricity and will serve the needs of thousands of homes in communities around the world.

Fig. 2.11 A 14 MW solar farm at Nellis Air Force Base in Nevada (USA). *Source* http://leadenergy.org/2010/07/new-cna-report-echoes-ael-findings-encourages-energy-innovation-in-the-dod/. Accessed February 2013

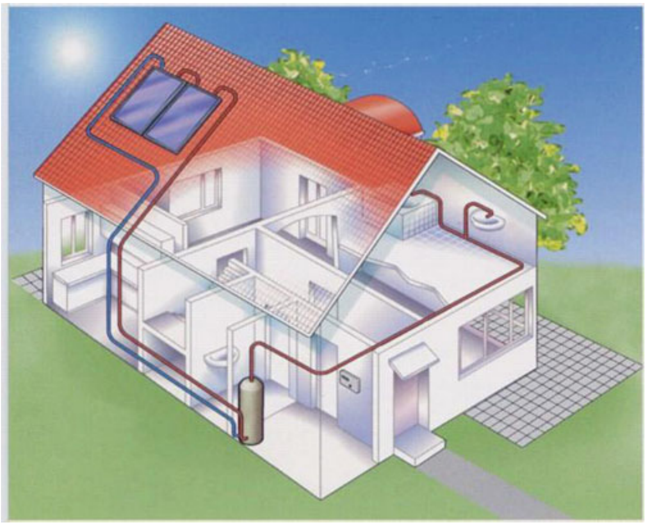


Fig. 2.12 Solar water heating schematics for a house. *Source* http://www.acbyj.com/water-heaters/the-arizona-sun-powers-your-solar-water-heater/. Accessed March 2013

Fig. 2.13 A solar water heater installed on the roof of a building. *Source* http://www.tapshop321.com/blog/index.php/326/solar-water-heating-for-the-home/. Accessed March 2013

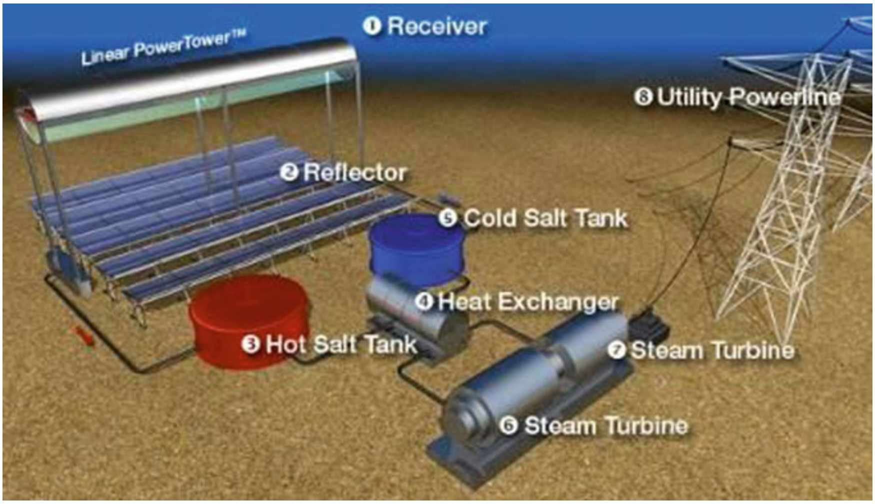


Fig. 2.14 Schematic for a parabolic concentrated solar power system by SkyFuel, Inc. *Source* www.skyfuel.com. Accessed February 2013

2.3.1.4 Solar Tubes

Solar tubes use optics to deliver lighting to dark parts of buildings, tunnels, and other public spaces (e.g., underground train stations). The installation of solar tubes can eliminate the need to use electricity for lighting during the day. The electrical energy generated during the day from other sources can then be stored for later use in the night or used to power non-lighting electrical appliances (Fig. 2.17).

Fig. 2.15 A solar concentrator—parabolic dish, Stirling engine. *Source* http://mcensustainableenergy.pbworks.com/w/page/20638019/Concentrating%20Solar%20Power. Accessed February 2013

Fig. 2.16 A concentrated solar power plant. *Source* http://www.ourbreathingplanet.com. Accessed February 2013

Fig. 2.17 A solar tube. *Source* http://inhabitat.com/solar-tube/. Accessed February 2013

2.3.1.5 Passive Solar Cooling and Heating

Buildings can be cooled or heated by an intelligent use of solar energy. What is required is smart architecture combined with a wise choice of building materials and environmentally sound landscaping. Smart architecture involves a careful design of key features of the building such as the envelope, its orientation, shape and size. Special materials for the walls, floors, windows, doors, vents, insulators and shades will dictate how the building handles heat and air movement. In good landscaping, strategically planted grasses, shrubs, and trees will influence the flow of air and heat. These intelligent design considerations exploit the local climate dynamics to achieve the desired cooling/heating of the building.

To cool the building, the walls, floors, doors, and windows become tools for blocking solar heat. The building is heated when the walls, floors, doors and windows are designed and constructed to absorb solar heat and distribute it throughout the building.

Figure 2.18 shows how these factors interplay at a building location for different seasons. In the tropics primary interest is in maintaining a cool temperature within the building. The challenge for the temperate regions of the world is more daunting since provision must be made for both winter and summer months. The building must be heated during the winter and cooled in the summer months. An intelligent design using passive solar cooling/heating techniques solves the problem.

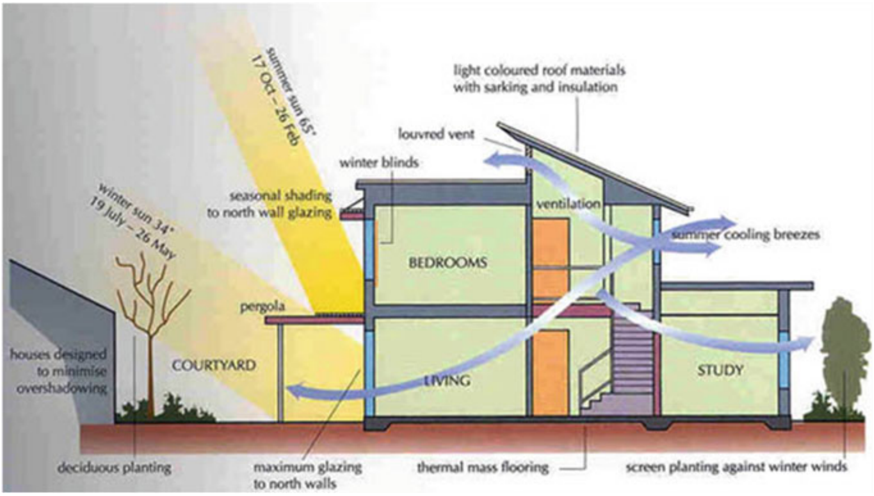


Fig. 2.18 Passive solar cooling and heating of a building. *Source* http://sustainableenergyz.files.wordpress.com/2012/04/passive-solar-energy.jpg

2.3.2 Wind

The global resource for wind is enormous. Figure 2.19 is the global wind speed map by 3TIER.[5] Wind turbines can generate electrical power at any site with a decent wind speed.

Scientists at the National Aeronautics and Space Administration (NASA) have been creating global satellite maps using years of data from NASA's QuikSCAT satellite. These maps reveal ocean areas where winds could produce energy. Figure 2.20 is an image of the QuikSCAT data that shows wind power density over global oceans for winter (top panel) and summer (lower panel) in the Northern Hemisphere. Red and white colors indicate areas where high energy is available. Blue color reflects lower energy.

To quote NASA[6]:

> Wind energy has the potential to provide 10–15 % of future world energy requirements, according to Paul Dimotakis, chief technologist at JPL. If ocean areas with high winds were tapped for wind energy, they could potentially harvest up to 500 to 800 W of wind power per square meter, according to Liu's research. Dimotakis notes that while this is less than peak solar power, which is about 1000 W/m^2 on Earth's surface when the sky is clear and the sun is overhead at equatorial locations, the average solar power at Earth's mid-latitudes under clear-sky conditions is less than a third of that. Wind power can be

[5] www.3tier.com

[6] Source: http://www.nasa.gov/topics/earth/features/quikscat-20080709.html. Accessed February 2013.

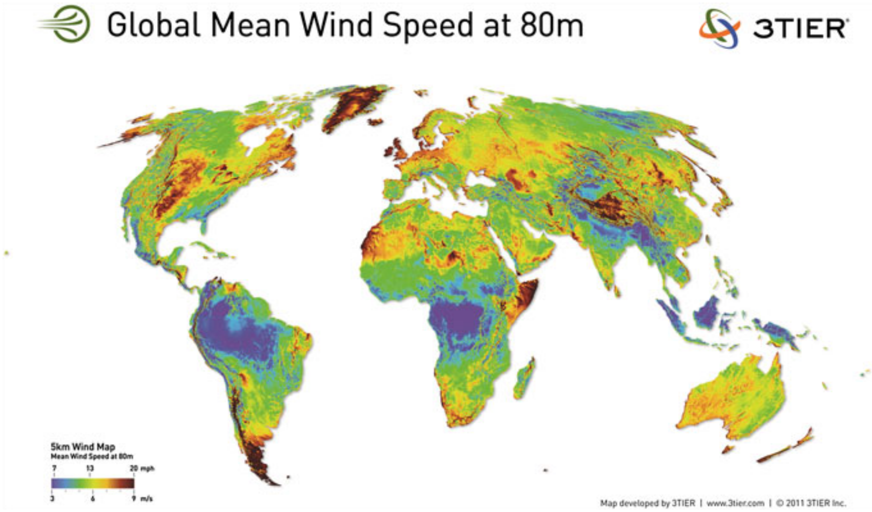


Fig. 2.19 Global mean wind speed at 80 m. Copyright © 2011 3TIER, Inc

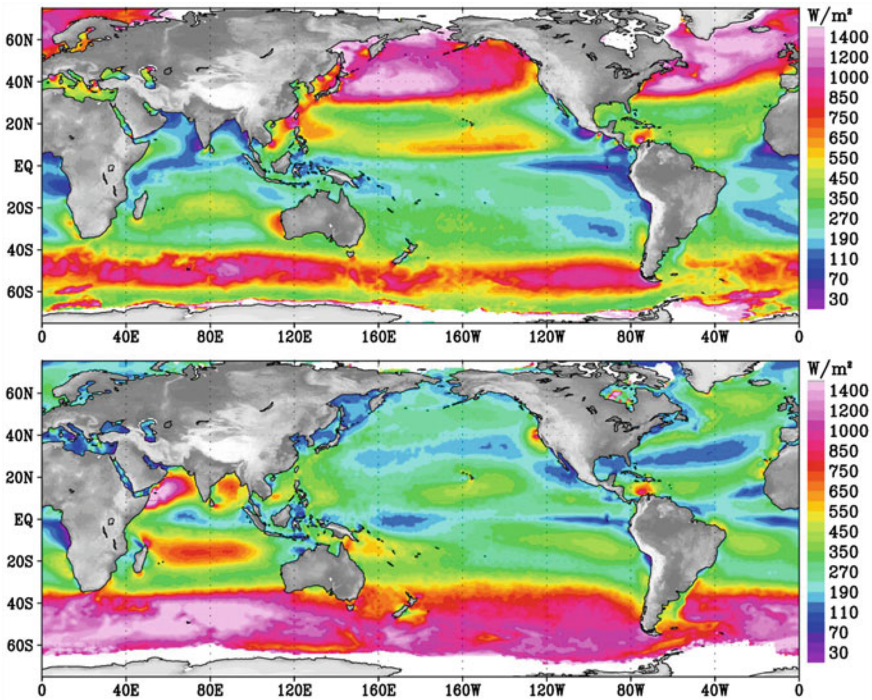


Fig. 2.20 NASA's image of QuikSCAT data of wind power density over global oceans. *Source* http://www.nasa.gov/topics/earth/features/quikscat-20080709.html. Accessed February 2013

converted to electricity more efficiently than solar power and at a lower cost per W of electricity produced.

Other parts of the world where wind energy can be significant include:

- high elevations such as the top of mountains and hills,
- mountain-valleys,
- desert regions and
- select planes with little vegetation and man-made obstacles where geography and topography combine to create the perfect condition for sustainable wind power.

Wind power is harnessed by using wind turbines to convert the mechanical energy in the wind into electrical energy. These turbines come in various sizes, shapes and configurations. With the significant progress made in wind turbine technology in the past couple of decades, communities of varying population, demographics and electrical power needs now have a wide spectrum of choices for their wind energy solutions.

There are two classes of wind turbines:

1. **Horizontal Axis Wind Turbines** (**HAWT**): These have one or more blades that turn around a horizontal axis when impacted by the wind. The propeller type 3-bladed wind turbine is the most common of this class. Majority of commercial wind turbine installations in the world today have been of the horizontal wind axis type. Manufacturers produce these wind turbines for different power specifications ranging from small (<250 KW, e.g., Vestas V25/200 KW wind turbines), to medium (<1 MW, e.g., Vestas V52/850 KW, Enercon E-44/900 KW wind turbines), to large (<5 MW, e.g., GE 1.5–77, 2.5–100 and 4.1–113 wind turbines) to mega size (>6 MW, e.g., Enercon 7.5 MW E126 wind turbine) (Figs. 2.21, 2.22, 2.23, 2.24 and 2.25).

Fig. 2.21 A wind farm of Vestas V52-850 KW wind turbines. *Source* www.vestas.com. Accessed March 2013

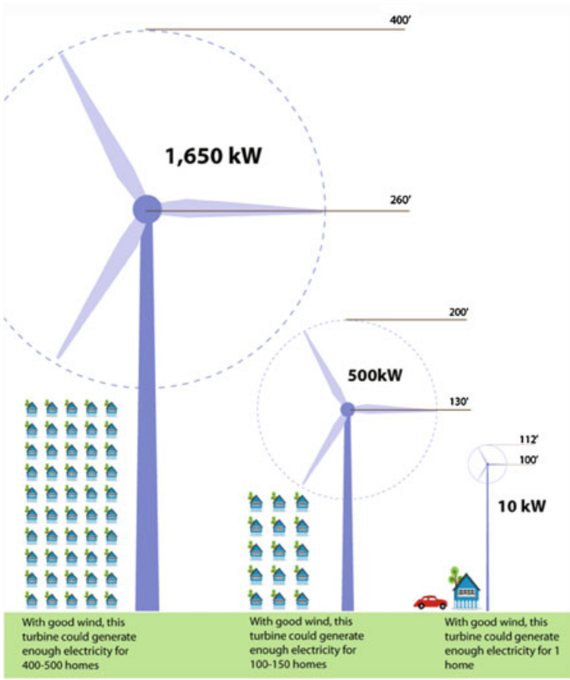


Fig. 2.22 A 3-bladed horizontal axis wind turbine. *Source* "Wind Energy" presentation by Richard Lawrence & Joe Rand RE/EE Education Conference Accessed February2013 through http://learn.kidwind.org/teach

2. **Vertical Axis Wind Turbines** (**VAWT**): The blades of this class of turbines turn around a vertical axis. One good example of a modern vertical axis wind turbine is the elegant 3-bladed, 6 KW rated qr5 by the UK-based manufacturer Quiet Revolution. An ambitious vertical axis wind turbine (Fig. 2.26) is being developed by another UK company, Wind Power Limited. The company plans to make the futuristic 10 MW Aero Generator X a critical part of their goal to generate 1,000 MW (or 1 GW) of wind power offshore by the year 2020.

2.3.2.1 Wind Turbine Power Generating Capacity

The amount of wind energy that can be harnessed depends on the velocity of the wind and the volume of the wind that can be captured by the turbine. Wind speed increases with altitude. Therefore, a turbine mounted on a tall tower will generate more power than an identical turbine on a shorter tower at the same location (Fig. 2.27). The power available in the wind is proportional to the cube of the velocity speed. If the wind speed is doubled the power generated will increase 8-fold!

Another factor that influences the power generating capacity of a wind turbine is the area swept by the blades. For a horizontal axis turbine, the swept area is proportional to the square of the diameter of the blade. Therefore, when the blade diameter is doubled the power generated is quadrupled.

Fig. 2.23 A wind farm with GE's 2.5–100 2.5 MW wind turbines. *Source* http://www.ge-energy.com/products_and_services/products/wind_turbines/ge_2.5_100_wind_turbine.jsp. Accessed February 2013

In order to capture more wind and generate more power, wind turbine manufacturers have been increasing the diameter of the blades over the years (Fig. 2.28). For example, Enercon's 7.56 MW E126 horizontal axis wind turbine has a rotor diameter of 126 m, hub height of 135 m, and a total height of 198 m. Wind Power's Aero Generator X has a span of 275 m. The deployment of large wind turbines in under developed regions of the world presents enormous difficulties for the following reasons:

1. the infrastructural and logistical challenges involved in transporting the huge blades;
2. the need for sophisticated equipment (e.g., huge cranes and/or helicopters that can handle large pay loads) to install the wind turbines;
3. the special knowledge required to adequately operate and maintain the entire power system.

For an *abulecentric* power system, we want the ease of:

1. transportation of equipment and construction material;
2. installation;
3. operation and maintenance.

Fig. 2.24 Germany's Enercon E126 7.56 MW wind turbine. *Source* http://www.enercon.de/en–en/66.htm. Accessed February 2013

As the power requirement of a given community increases, the need for a farm of wind turbines may be inevitable. A wind farm has been described as the crop of the 21st century (Flowers 2007) (Fig. 2.29).

2.3.2.2 A New Idea in Wind Farm Implementation

There is a fascinating development in the wind energy sector that is highly favorable to an *abulecentric* wind power system. Recent investigations (Whittlesey 2010; Whittlesey et al. 2010; Dabiri 2011) have shown that a wind farm consisting of much specially arranged smaller VAWTs generates significantly more (actually an order of magnitude larger) power per unit area than that produced from a farm populated with the traditional HAWTs. The higher performance is achieved because the VAWT layout can be arranged such that the turbines extract energy from adjacent turbine wakes and vertically from above the wind farm.

The following is a direct quote from the Whittlesey et al. (2010) paper:

> Most wind farms consist of horizontal axis wind turbines (HAWTs) due to the high power coefficient (mechanical power output divided by the power of the free-stream air through the turbine cross-sectional area) of an isolated turbine. However when in close proximity

Fig. 2.25 UK-based Quiet Revolution's vertical axis wind turbine qr5

to neighboring turbines, HAWTs suffer from a reduced power coefficient. In contrast, previous research on vertical axis wind turbines (VAWTs) suggests that closely spaced VAWTs may experience only small decreases (or even increases) in an individual turbine's power coefficient when placed in close proximity to neighbors, thus yielding much higher power outputs for a given area of land.

Fig. 2.26 Futuristic 10 MW 2-bladed vertical axis wind turbine Aero Generator X by UK-based Wind Power Ltd. *Source* http://www.windpower.ltd.uk/. Accessed February 2013

According to (Dabiri 2011), who referenced (Sørensen 2004; Hau 2005; MacKay 2009):

> To maintain 90 % of the performance of isolated HAWTs, the turbines in a HAWT farm must be spaced 3–5 turbine diameters apart in the cross-wind direction and 6–10 diameters apart in the downwind direction. The power density of such wind farms, defined as the power extracted per unit land area, is between 2 and 3 W per sqm (Fig. 2.30).

McDermott (2011) wrote the following in an online environmental magazine:

> VAWTs are ideal, John Dabiri says, because they can be positioned very close to one another. This let them capture nearly all of the energy of the blowing wind and even wind energy above the farm. Having every turbine turn in the opposite direction of its neighbors, the researchers found, also increases their efficiency, perhaps because the opposing spins decrease the drag on each turbine, allowing it to spin faster (Dabiri got the idea for using this type of constructive interference from his studies of schooling fish).

This groundbreaking discovery of the huge performance advantage of a farm of VAWTs over the conventional HAWT-populated wind farm is good news for *abulecentric* wind power development. Apart from the improved power generation capability, a farm of VAWTs brings additional benefits. These include:

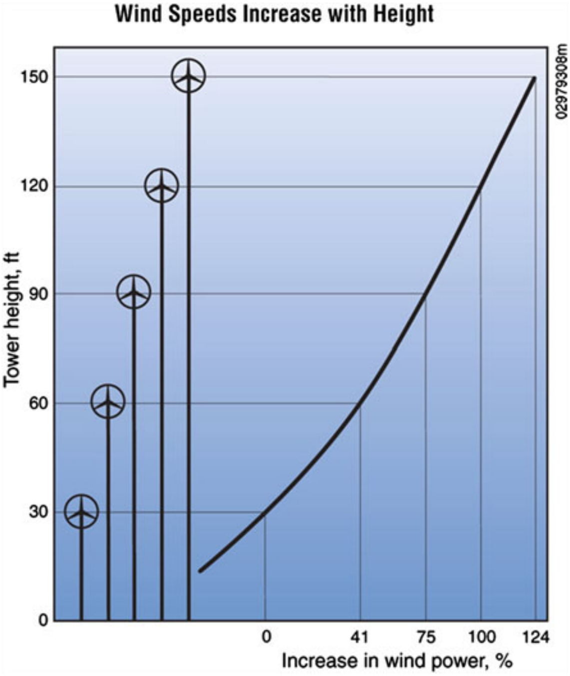


Fig. 2.27 Influence of elevation on the power generated from a wind turbine. *Source* http://www.uscg.mil/d1/SFOSouthwestHarbor/innovation/wind/wind_101.asp. Accessed March 2013

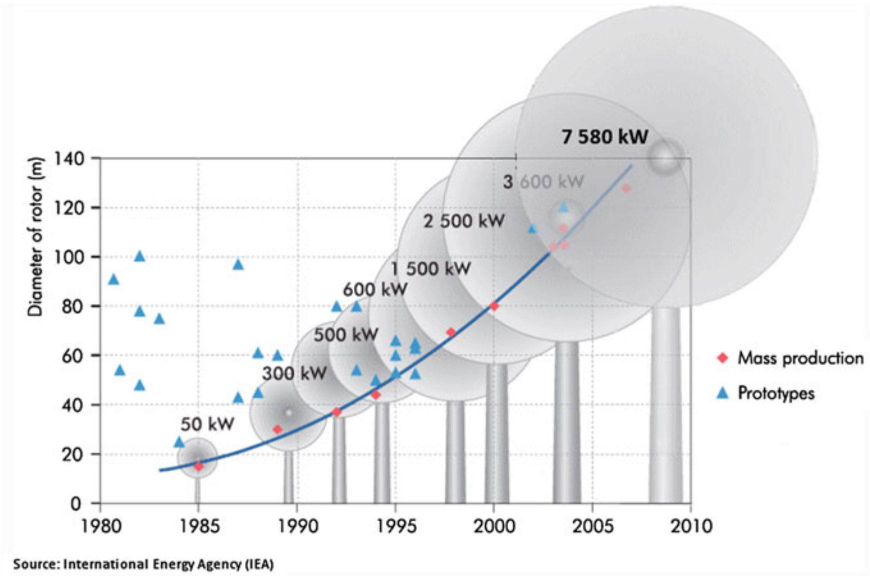


Fig. 2.28 Evolution of wind turbine diameter since the 1980s. *Source* International Energy Agency (IEA)

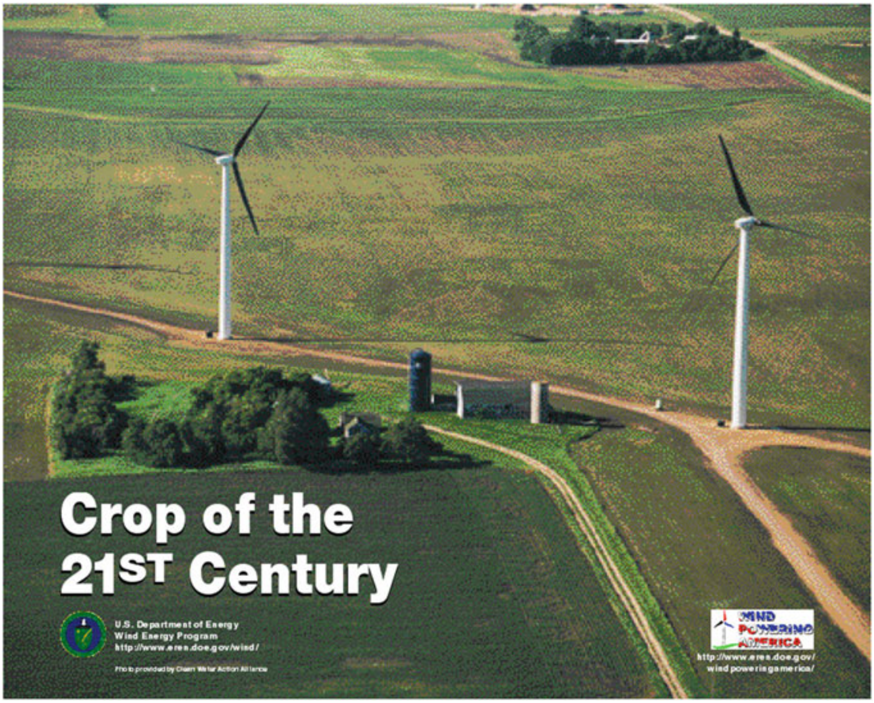


Fig. 2.29 Wind farm—“Crop of the 21st Century”. *Source* http://www.nrel.gov/wind/

1. Reduced acquisition cost—the VAWTs are simple run-of-the-mill turbines without the complexity and expense associated with the larger HAWTs.
2. Reduced demand for land area—the farm of VAWTs produces more power per unit area than a farm of HAWTs. Wind farms consisting of the traditional HAWTs require substantial land resources in order to separate individual turbines from the adjacent wind turbine wakes (Dabiri 2011).
3. Less threatening environmental impact (e.g., noise pollution, imposing structures constituting an eyesore etc.)—the height of the typical large HAWT (over 100 m) can be over 10 times that of a typical VAWT.
4. Ease of installation—no need for heavy duty land transporters, huge cranes and helicopters such as required to install HAWTs.
5. Ease of maintenance—the blades are reachable and the power electronics components are on the ground level unlike the case of a large HAWT where they are at a height of over 100 m above the ground.
6. Opportunity to develop local manufacturing industry for the turbines and the power electronics components.

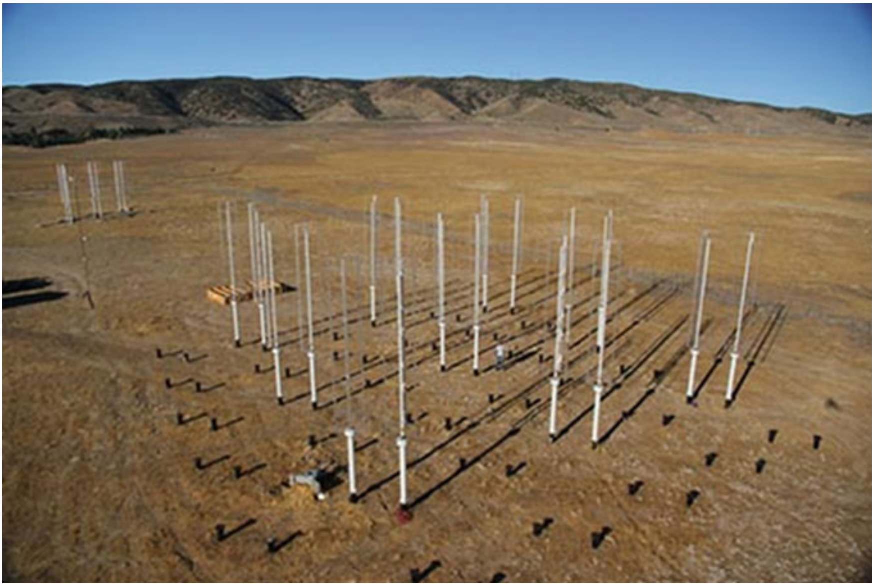


Fig. 2.30 An experimental farm of vertical axis wind turbines used in Dabiri (2011) work. *Photo* John Dabiri/Caltech

2.3.3 Hydro

Hydro power plants convert the energy in flowing water into electricity. The flow can be initiated using an opening at or near the base of a body of water (e.g., lakes, reservoirs). Alternatively, the flow may be due to the natural flow of a river or stream.

Conventional Hydropower Plants. When an opening is made at the base of a water container, a jet of water will be the result. The discharge rate of the water increases with the height of water above the opening. In a conventional hydropower plant, a turbine generator is specially positioned to convert the kinetic energy possessed by the jet into electricity (Fig. 2.31).

Run-of-the-River Hydro Power Plants: In this case, the kinetic energy possessed by virtue of the flow of the river or stream is converted into electricity. Unlike the hydroelectric dam, it is not necessary to impound the water. Run-of-the-river hydro power plants often fall into the class of low-head hydro systems.

The Water Program of the United States Department of Energy provides the following classification for hydropower systems (US DOE 2013):

- Large Hydropower—capacity of more than 30 MW
- Small Hydropower—capacity ranging from 100 KW–30 MW
- Micro Hydropower—capacity up to 100 KW.

For most developing communities around the world, small and micro hydropower systems will be sufficient for the electrical power needs (see Sect. 2.4 on Community Power Requirements).

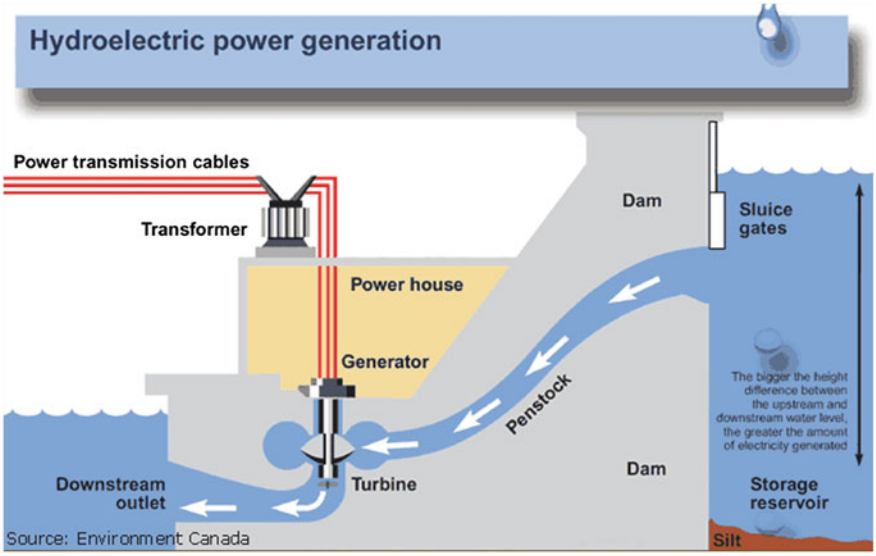


Fig. 2.31 Schematic of a hydroelectric power plant. Accessed February 2013 through http://ga.water.usgs.gov/edu/wuhy.html

Figure 2.32 shows the potential annual hydro energy (measured in terra watt-hours) and 2004 hydropower production in regions of the world. Only North America, Western Europe and Australia have hydropower production that is a significant portion of their potential. Africa and South East Asia have not taken full advantage of their hydro resources.

2.3.3.1 Modern Small Hydro Systems for Abulecentric Development

We describe below two small hydro systems that are excellent for *abulecentric* power development. These hydro systems fall into a special class of the *run-of-the-river* type popularly referred to as "kinetic hydropower" systems. Apart from using the natural flow of rivers, kinetic hydro power systems can also use the tidal currents created in water basins.

1. **Free Flow System**. This small hydropower system is manufactured by New York based Verdant Power. The system is a small hydro plant that uses three-bladed, underwater horizontal-axis turbines to generate electricity from the currents of tides, rivers and manmade channels. Each of the 5 Free Flow turbines used for the 2006–2008 Roosevelt Island Tidal Energy (RITE) demonstration project (CanmetENERGY-Ottawa 2010) had a rated capacity of 35 KW at mean water current of 2.1 m/s. Free Flow System is scalable and adaptable to different geographical regions and population areas (Figs. 2.33 and 2.34).

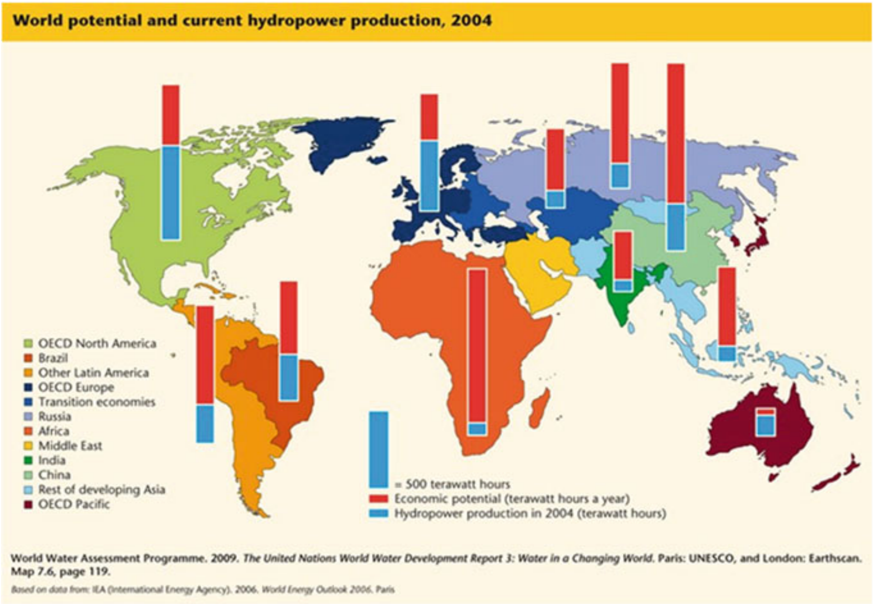


Fig. 2.32 World potential and 2004 hydropower production. *Source* http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/facts-and-figures/all-facts-wwdr3/fact-6-hydropower/. Accessed February 2013

2. **Smart Hydro Power**. Germany-based Smart Hydro Power (SHP) launched their 5 KW kinetic hydropower turbine in April 2011. The maximum 5 KW power output is rated at river flow rate of 2.75 m/s (Fig. 2.35).
   Key advantages of the Smart Hydro Power System include:
   (a) Ease of transportation even to rural areas and remote regions of the world (Fig. 2.36).
   (b) Ease of installation (Fig. 2.37).
   (c) Minimal impact on the environment (Fig. 2.38).
   (d) Scalability—ability to combine multiple 5 KW units to generate power for larger communities (Fig. 2.39).
   (e) No obstruction to river traffic (Fig. 2.40).
3. **Gorlov Helical Turbine** (**GHT**). This turbine, for which Professor Alexander M. Gorlov of Northeastern University (USA) has received several patents (Gorlov, Unidirectional helical reaction turbine operable under reversible fluid flow for power systems, 1995; Gorlov, System for providing wind propulsion of a marine vessel using a helical turbine assembly, 2001; Gorlov, Method for maintaining flotation using a helical turbine assembly, 2001), has highly efficient blades shaped as helical foils.

Fig. 2.33 Verdant Power's Free Flow System. *Source* http://verdantpower.com/what-technology/

Key elements of GHT are described in Gorlov (1998). Gorlov and his research collaborators (Gorban et al. 2001) developed an elegant mathematical model for estimating the maximum efficiency of turbines in a free (non-ducted) fluid. They showed that the helical turbine is more efficient (up to 35 %) than the horizontal axis propeller-type (maximum 30 % for free fluids), at least in water applications. In fact, a number of commercial wind turbines, e.g., Quiet Revolution (Quiet Revolution Ltd 2013), Turby (Turby Emerging Energy) and Urban Green Energy (Urban Green Energy), have adopted helical twist blade design similar to GHT to solve the vibration issues that impair the performance of Darrieus[7]-type vertical axis wind turbines (Fig. 2.41).

GHT has been favored in several commercial projects and rural development initiatives since the invention. A 6-bladed GHT was installed on the mouth of the Amazon River in the Tidal Energy Project (Fig. 2.42).

Ocean Renewable Power Company (ORPC) of Maine (USA) has developed a number of power generators (Figs. 2.43, 2.44, 2.45, 2.46) incorporating modular GHT-type turbines. Different units have been developed for small rivers, shallow tidal and deep tidal and ocean current sites.

[7] Darrieus wind turbines have vertical axis blades shaped like an eggbeater. These turbines have been plagued with large torque and debilitating cyclic stresses on the towers.

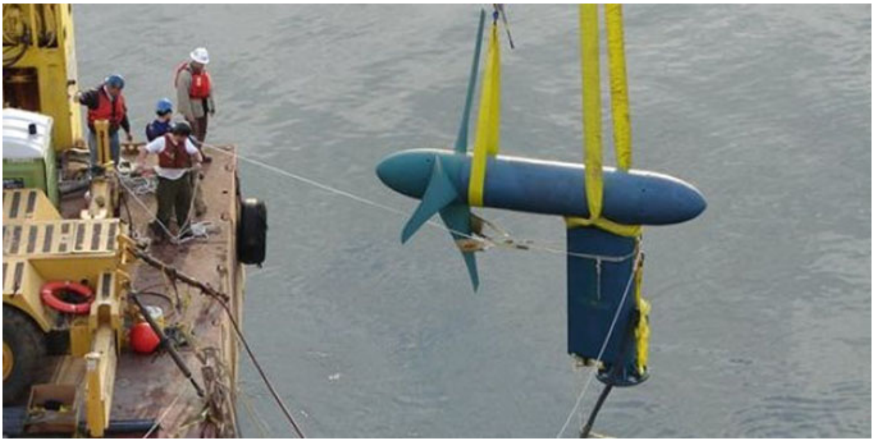


Fig. 2.34 Installing Free Flow System turbine in East River, New York, NY (Dec 2006)—*Credit* Kris Unger/Verdant Power, Inc

Fig. 2.35 The Smart Hydro Power System. *Source* Modular Kinetic Hydro Power, publication by Smart Hydro Power

2.3.4 Biomass

Biomass is organic matter—the biological material obtained from organisms. Biomass power ("biopower") involves the direct or indirect use of biomass as fuel to generate electricity. According to (NREL 2013):

> Biopower system technologies include direct-firing, cofiring, gasification, pyrolysis, and anaerobic digestion. Most biopower plants use direct-fired systems. They burn bioenergy feed stocks directly to produce steam. This steam drives a turbine, which turns a generator

Fig. 2.36 Transporting a Smart Hydro Power System. *Source* Modular Kinetic Hydro Power, publication by Smart Hydro Power

Fig. 2.37 Installing a Smart Hydro Power System. *Source* Modular Kinetic Hydro Power, publication by Smart Hydro Power

> that converts the power into electricity. In some biomass industries, the spent steam from the power plant is also used for manufacturing processes or to heat buildings. Such combined heat and power systems greatly increase overall energy efficiency.

Pyrolysis deserves a special treatment for *abulecentric* community biopower generation. Pyrolysis (a combination of "pyros", the Greek word for fire and

Fig. 2.38 Smart hydro power installed in a neighborhood river. *Source* http://www.smart-hydro.de/. Accessed February 2013

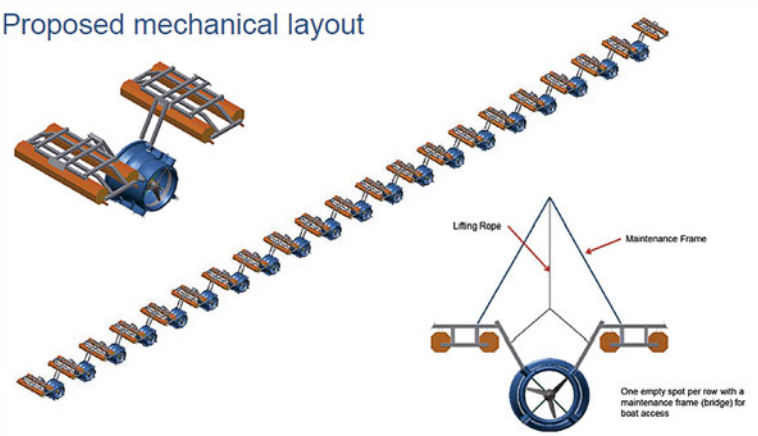


Fig. 2.39 Combining smart hydro power turbines. *Source* Modular Kinetic Hydro Power, publication by Smart Hydro Power

"lysis" which is derived from the word dissolution) is the decomposition of biomass and other organic materials at high temperatures in the absence of air. Pyrolysis produces pyro-char [(a solid fuel useful as a fertilizer (Kram 2013))]; pyro-liquid (which can be distilled into fuel for automotive use) and pyro-gases (fuel for electrical power generators).

Pyrolysis is emerging as an excellent technology for generating energy from diverse wastes such as sewage sludge, food scraps, agricultural wastes, wood, plastics and tires. One tonne of waste has the potential of generating 700 kW h of

Fig. 2.40 Smart Hydro Power. No obstruction to river traffic. *Source* http://www.smart-hydro.de/. Accessed February 2013

Fig. 2.41 Gorlov helical turbine. *Source* http://www.flickr.com/photos/european_patent_office_epo/5715578194/sizes/l/in/photostream/. Accessed April 2013

Fig. 2.42 6-blade GHT installed in the Amazon. *Source* http://www.globalcoral.org/

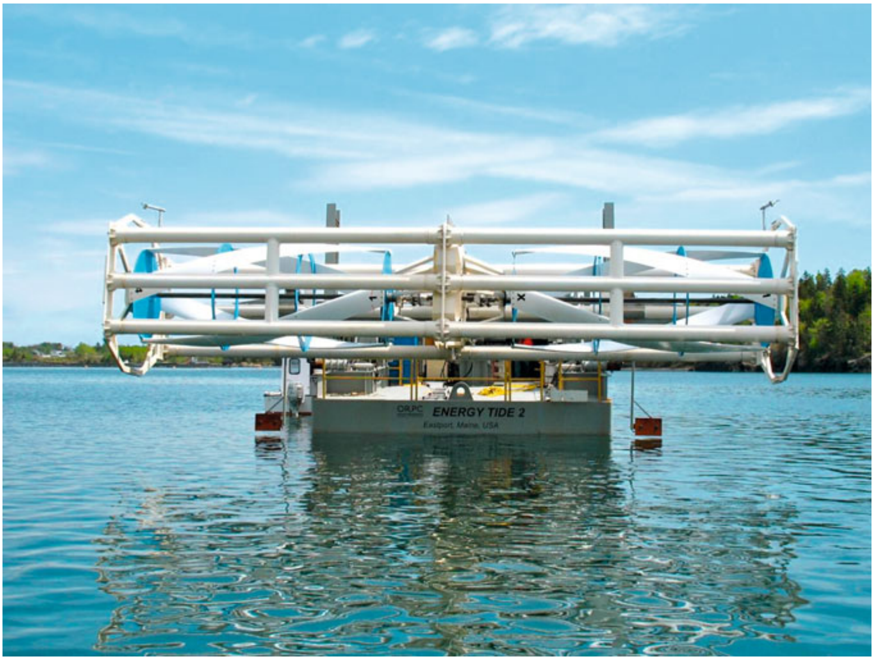


Fig. 2.43 ORPC's Beta Power Generation Turbine Unit. *Source* http://greenenergymaine.com/news/water-power

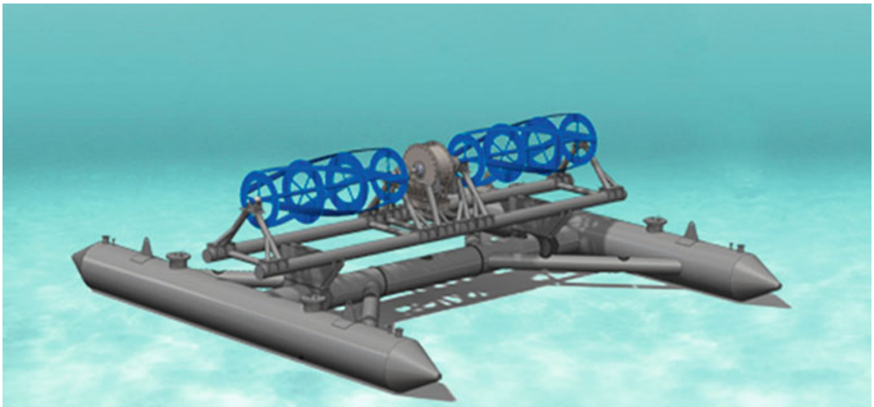


Fig. 2.44 ORPC's RivGen^{TM} power system for small river sites. *Source* www.orpc.co

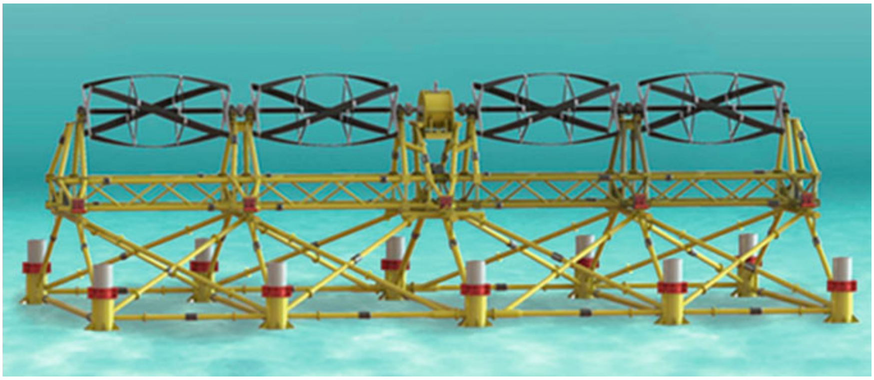


Fig. 2.45 ORPC's TidGen^{TM} power system for shallow tidal and deep river sites. *Source* www.orpc.co

electricity. A pyrolytic facility fed with 100,000 tonnes of waste per annum can supply the electrical energy needs of 10,000 average homes.

Pyrolytic plants have several advantages over other waste-to-energy systems. The Swiss company, Pyromex (PYROMEX AG 2007), lists the following advantages for their pyrolytic waste-to-energy power plant:

- Ecology
  - No dangerous residues, nothing to dispose of after treatment
  - No harmful emissions to the atmosphere
  - Treating of all kinds of waste, including hazardous and toxic material
  - Meeting the highest and most severe environmental rules and regulations

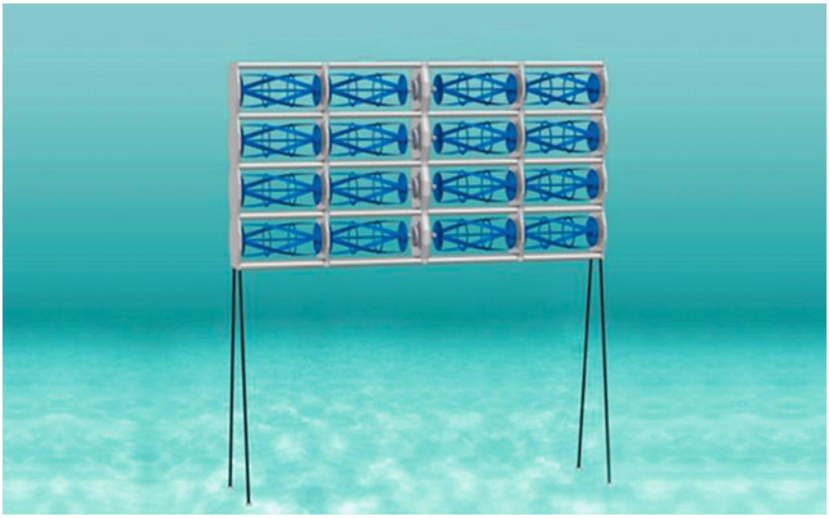


Fig. 2.46 ORPC's OCGen^{TM} power system for deep tidal waters and strong ocean current sites. *Source* www.orpc.co

- Efficient
  - Modular, upgradeable system, starting at 10 t per day upward
  - A fraction of the size of common waste treatment plants
  - Fitting into a small, compact, two level construction
  - No smoke stack necessary
  - Accelerated waste treatment processing
  - All valuable contents of the waste are recoverable
  - Different energy recovery technologies possible
  - Various energy utilization possible
- Economical
  - Lower investment costs compared to common waste treatment plant
  - Fewer costs for treatment and maintenance
  - Low energy requirements
  - Greater power output per ton than that of common waste treatment plants
  - Profitable business, not just a break-even operation (Figs. 2.47, 2.48, 2.49).

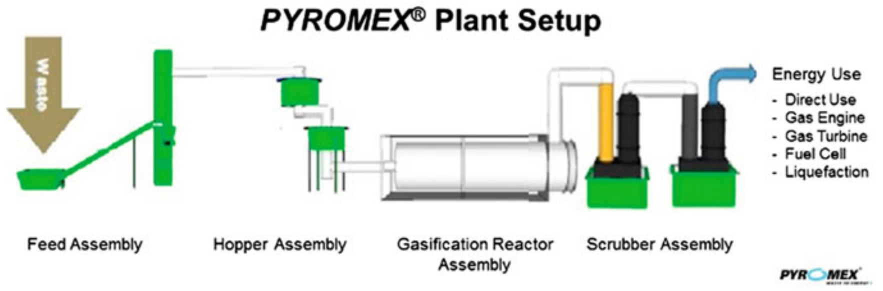


Fig. 2.47 PYROMEX pyrolytic waste-to-energy plant setup. *Source* http://www.pyromex.com/index.php/en/plants

Fig. 2.48 PYROLEX Class A plant. Capacity 5 tons/day. *Source* http://www.pyromex.com/index.php/en/plants

Fig. 2.49 PYROLEX Class B plant. Capacity 25 tons/day. *Source* http://www.pyromex.com/index.php/en/plants

Table 2.1 Continuous plant power as a function of average monthly energy usage per home

		Average monthly energy usage (KW h) per home					
		200	300	500	1,000	2,000	3,000
		Number of individual homes served					
Continuous plant power (KW)	**100**	360	240	144	72	36	24
	200	720	480	288	144	72	48
	500	1,800	1,200	720	360	180	120
	1,000	3,600	2,400	1,440	720	360	240
	1,500	5,400	3,600	2,160	1,080	540	360
	2,500	9,000	6,000	3,600	1,800	900	600
	5,000	18,000	12,000	7,200	3,600	1,800	1,200

2.4 Community Power Requirements

The power requirement of a given community is obviously a function of the population, number of housing units, average number of residents per housing unit, the socio-economic condition and the industrialization level of the community. Table 2.1 shows the continuous power requirement in a residential community as a function of the average monthly energy usage per home.

In underdeveloped societies the average monthly energy demand (e.g., to power a few light bulbs, radios and charge cell phones) will probably not exceed 200 kW h per home. A 1 MW power plant will easily meet the needs of a community consisting of almost 4,000 homes. In more affluent societies such a power plant might supply the needs of almost 400 homes where the average monthly usage is close to 2,000 kW h per home.

2.5 Community Energy Storage

Intermittency is a major challenge in the use of renewable energy systems. The challenge is particularly acute in off-grid power installations. For example, sunlight is available only for a few hours every day at a given location on earth. This makes uninterruptible solar power generation impossible to achieve without a supporting system to provide power during the night. Furthermore, cloudy days can extend to several days rendering a solar power system unproductive. For hydro power stations, dry seasons can affect the reservoir levels or river flows thereby rendering water turbines inoperative.

Energy storage is the solution to the intermittency problem. A critical component of an *abulecentric* power system is **community energy storage** (CES). This is a concept that is growing globally in both developed and developing regions.

For developing countries, where community power systems are the most logical option, CES is necessary for off-grid power installations. CES is used for the

Table 2.2 Community energy storage requirement as a function of average energy usage per home

		Average monthly energy usage (KW h) per home					
		200	300	500	1,000	2,000	3,000
		Number of individual homes served					
Community energy storage capacity (MW h)	**2**	150	100	60	30	15	10
	4	300	200	120	60	30	20
	6	450	300	180	90	45	30
	8	600	400	240	120	60	40
	10	750	500	300	150	75	50
	12	900	600	360	180	90	60
	14	1,050	700	420	210	105	70

effective storage of the energy produced from intermittent renewable sources. In the ultimate *abulecentric* deployment model, storage units are distributed in such a way that each unit serves the needs of a few buildings at any given time.

For developed countries, CES is necessary to balance the load of the massive power grid infrastructure. Electricity usage in industrialized countries tends to peak during the day and low in the night. The most economical approach to power supply is to store the excess energy generated during the night and make the surplus available during the peak hours of the day. Furthermore, in developed economies, the integration into the grid of pockets of intermittent renewable power generators at different locations constitutes major challenges for power electronics equipment. CES units help to stabilize neighborhood grids while also supplying the required electricity when there is power outage or during peak power spikes.

As in the case of the continuous electrical power, the community energy storage requirement is also a function of the average energy consumption per home. With a given capacity of the CES, more homes in a poor community will be served than in an affluent community. Table 2.2 shows the number of individual homes within a given community that will be served by various capacities (MW h) of a community energy storage system. The number of homes served is determined after assuming that the CES goes through a 50 % depth of discharge (DOD) every day in an average 30-day month.

Current state-of-the-art technologies for community energy storage are presented below.

2.5.1 Current Energy Storage Technologies

The classification of energy storage technologies is done according to the form in which the energy is stored (IEC: Electrical Energy Storage Project Team 2011):

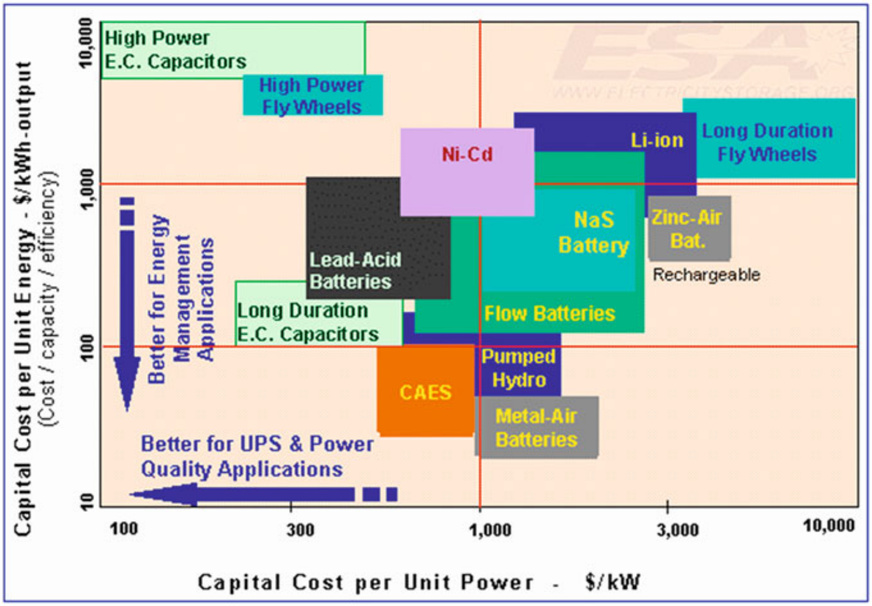


Fig. 2.50 Capital cost for energy storage technologies. *Source* http://www.electricitystorage.org/images/uploads/static_content/technology/technology_resources/capital-cost_large.gif. Accessed February 2013

1. Electrochemical—e.g., "secondary batteries" (e.g., lead-acid, lithium, sodium sulfide, nickel–cadmium, nickel-metal hydride etc.) and "flow batteries".
2. Chemical—e.g., hydrogen fuel cell
3. Mechanical—e.g., pumped hydro, compressed air, fly wheel
4. Electrical—e.g., capacitors, super capacitors and superconducting magnetic energy storage
5. Thermal—e.g., pumped heat, molten salt.

The chart on Fig. 2.50, from the Electricity Storage Association (EAS), shows the capital cost of the various energy storage technologies, while Table 2.3 shows their relative advantages and disadvantages.

We have selected a few of these energy storage technologies that are relevant to the type of CES that works best with *abulecentrism*. Some of the technologies (e.g., lead-acid batteries) are mature and obtainable in many regions of the world. Certain technologies (e.g., lithium-ion-based systems) are playing key roles in new small-scale, medium-scale and large-scale installations. Some of the highlighted technologies (e.g., Ericsson cycle-based pumped heat energy storage, Green Power Island pumped hydro) are still under development and have not received the rigorous testing and validation required for commercial installations.

Table 2.3 Current energy storage technologies

Storage technologies	Main advantages (relative)	Disadvantages (relative)	Power application	Energy application
Pumped storage	High capacity, low cost	Special site requirement		●
CAES	High capacity, low cost	Special site requirement, need gas fuel		●
Flow batteries PSB VRB ZnBr	High capacity, independent power and energy ratings	Low energy density	◑	●
Metal-air	Very high energy density	Electric charging is difficult		●
NaS	High power & energy densities, high efficiency	Production cost safety concerns (addressed in design)	●	●
Li-ion	High power & energy densities, high efficiency	High production cost, requires special charging circuit	●	○
Ni–Cd	High power & energy densities, efficiency		●	◑
Other advanced batteries	High power & energy densities, high efficiency	High production cost	●	○
Lead-acid	Low capital cost	Limited cycle life when deeply discharged	●	○
Flywheels	High power	Low energy density	●	○
SMES, DSMES	High power	Low energy density, high production cost	●	
E. C. capacitors	Long cycle life, high efficiency	Low energy density	●	◑

Source http://www.electricitystorage.org/technology/storage_technologies/technology_comparison. Accessed February 2013

2.5.1.1 Electrochemical Batteries

A battery is any device in which energy is stored for later use. Electrochemical batteries have cells that convert stored chemical energy to electrical energy. Primary batteries transform the stored chemical energy irreversibly into electrical energy. A primary battery, once used, will be disposed. Secondary batteries are rechargeable. Batteries used for community energy storage must be rechargeable. Furthermore, these must be "deep-cycle batteries" defined as batteries which can undergo regular discharges that will deplete a significant amount of the stored energy. Generally, most deep-cycle batteries are designed to be capable of discharging between 50 and 80 % of the stored energy. The underlying chemistry is a major determinant of critical battery characteristics (e.g., energy density, depth of discharge and life cycle).

- **Lead-acid Batteries**. These are the most common and perhaps the most affordable deep cycle battery for community energy storage installations. According to

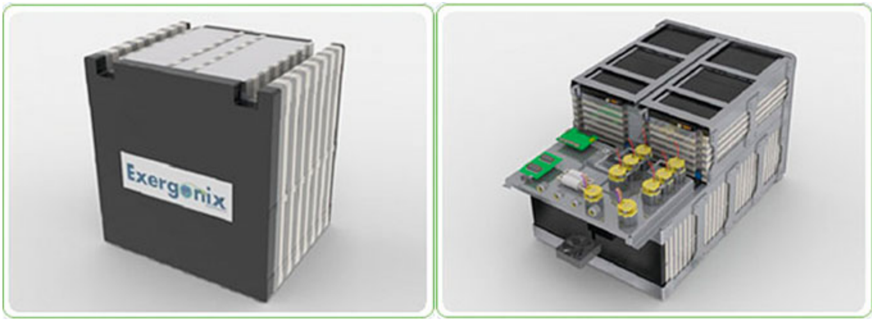


Fig. 2.51 Energonix nano cell-based battery module and CES. *Source* http://www.exergonix.com/battery_energy_storage_systems.php. Accessed February 2013

Battery Council International[8]: "*An established infrastructure of lead mining and mature manufacturing has made lead-acid one of the most cost effective energy storage technologies. Lead-acid comes out on top as the lowest cost of energy and power output per kilowatt-hour*." Lead-acid batteries come in three classes:

- Flooded—these have removable caps. These batteries require regular maintenance as the level of the electrolyte must be checked frequently and the water loss from electrolysis must be replenished.
- Absorbed Glass Mat (AGM)—the electrolyte is absorbed in a fine fiber-glass mat.
- GEL (the acid is "gelled" by the addition of silica gel)—the cell has the electrolyte mixed with silica dust to form a gel.
  AGM and GEL Batteries are the sealed and Valve Regulated Lead Acid (VRLA) batteries. VRLA batteries do not require regular addition of water to the cells, and vent less gas than flooded lead-acid batteries. They are described as "maintenance free" unlike flooded batteries.

- **Lithium Ion Batteries**. Lithium Ion batteries are perhaps the most popular energy storage technologies in the world today. Many manufacturers are developing large integrated Lithium Ion based battery systems suitable for CES.
  - Energonix Incorporated, a US company, has designed a CES using lithium nano-material based cells. The Energonix CES system is available from 1 to 100 kW h modules. The CES uses the same technology implemented in the company's 1 MW/500 kW h Battery Energy Storage System (BESS). The BESS, together with the storage units and power electronics, is built inside a 45-ft enclosure (Figs. 2.51, 2.52, 2.53).
  - Xtreme Power® (XP®), a US company, designs, engineers, manufactures, and operates integrated energy storage and power management systems. Xtreme

[8] http://batterycouncil.org/?page=Energy_storage. Accessed February 2013.

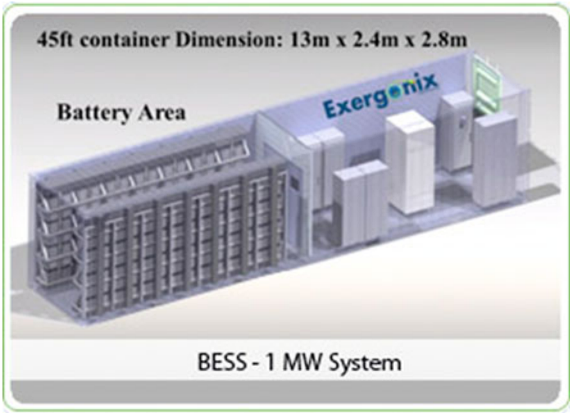


Fig. 2.52 Energonix Battery Energy Storage System. *Source* http://www.exergonix.com/battery_energy_storage_systems.php. Accessed February 2013

Fig. 2.53 Energonix grid-scale energy storage system. *Source* http://www.exergonix.com/battery_energy_storage_systems.php. Accessed February 2013

Power has produced a lithium based battery system suitable for CES. Contained in a 40-ft enclosure, the Xtreme Power system has a single 1 MW h rack of Lithium Ion batteries and two sections with 1.5 MW power conversion module. The latter is required to convert energy stored in the batteries into the electrical power required for the appliances or "electrical load" that will utilize the energy (Fig. 2.54).

Fig. 2.54 Xtreme Power's lithium ion battery system. *Source* http://www.xtremepower.com/

Fig. 2.55 Xtreme Power's 15 MW/10 MW h battery pack installed for Kahuku 30 MW wind farm in Oahu, Hawaii. *Source* http://www.xtremepower.com/projects/wind.php. Accessed February 2013

The Xtreme Power System installed for the 30 MW Kahuku Wind Farm in Oahu, Hawaii has a 10 MW h energy storage capacity (Fig. 2.55).

– A123, a developer and manufacturer of advanced lithium-ion batteries and battery systems, has the Grid Storage Solution (GSS) which is being promoted

Fig. 2.56 A123's Grid Storage Solution (*GSS*). *Source* http://www.a123systems.com/grid-energy-storage-system.htm. Accessed February 2013

for integrating renewable power sources such as wind and solar into the existing grid infrastructure (Figs. 2.56 and 2.57).

– Although developed specifically for the needs of the utility companies, S & C's Pure Wave CES uses lithium ion based chemistry and it can be deployed in developing communities where the basic energy needs are much lower than those of more advanced countries. For example, in low-income communities where the average home monthly energy consumption is less than 100 kW h, a single 25–75 kW h energy rated PureWave CES unit, integrated with a renewable energy system, will conveniently meet the uninterruptible power needs of a small village of a few residential homes (Fig. 2.58).

2.5.1.2 Pumped Hydro Energy Storage (PHES)

The bulk of the world's stored electrical energy is in the form of PHES (Dötsch 2007). A traditional PHES involves two water reservoirs at different elevations. To store the electrical energy water is pumped from the reservoir at the lower elevation to the one at the higher elevation. To generate electricity the water is made to flow from the upper reservoir to the lower one through a turbine generator. PHES tends to be cost effective and reliable since the system is capable of going through large charge–discharge cycles. The major drawback for PHES is the special consideration that must be given to location's geography and topography.

Fig. 2.57 A-123's 2 MW, 500 kW h lithium ion system. *Source* http://www.a123systems.com/ Accessed February 2013

Fig. 2.58 S & C's PureWave® community energy storage system. *Source* http://www.sandc.com/products/energy-storage/ces.asp. Accessed February 2013

One profound idea for PHES is coming out of Denmark. Green Power Island is the PHES system proposed by Copenhagen-based architectural firm Gottlieb Paludan. Green Power Island will use seawater pumped into a lagoon-like reservoir built into an artificial island (Figs. 2.59 and 2.60).

Fig. 2.59 Green Power Island. *Source* http://www.greenpowerisland.dk/. Accessed February 2013

When demand is low, pumps driven by wind turbines empties the reservoir. At peak periods, water is allowed to flow back into the reservoir, through turbines thus generating electricity to meet the rising demand.

2.5.1.3 Pumped Heat Energy Storage (PHES)

Energy is stored in the form of heat for this storage system. For example, consider the case of the heat generated from Concentrated Solar Power (CSP) plants

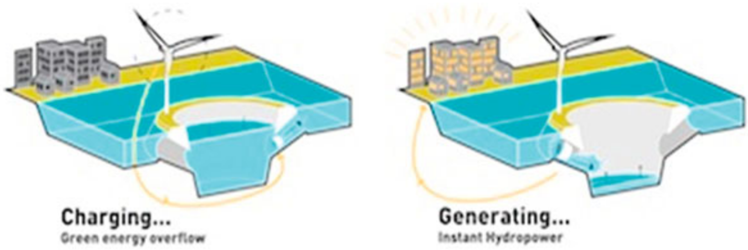
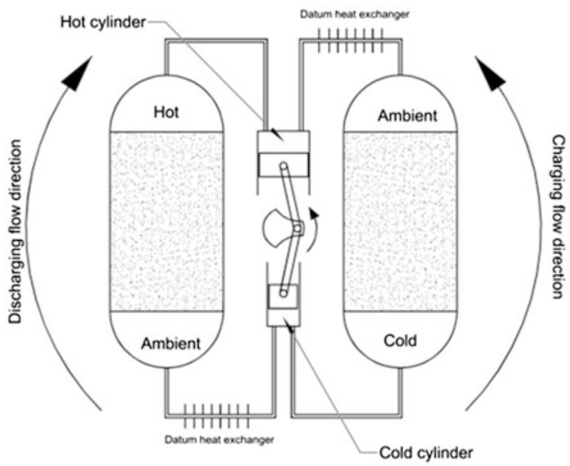


Fig. 2.60 Green Power Island. *Source*: http://www.greenpowerisland.dk/. Accessed February 2013

Fig. 2.61 Isentropic's pumped heat energy storage system. *Source* http://www.isentropic.co.uk/our-phes-technology. Accessed February 2013



producing heat as earlier described. The heat can be stored in a molten salt by direct solar radiation. To generate electricity the molten salt is used to produce steam that is passed through a steam turbine.

An innovative PHES system is being promoted by Isentropic Ltd in the United Kingdom. Isentropic's storage system uses two large containers of mineral particulate. Electricity is used to pump heat from one vessel to the other resulting in the first container cooling to around −160 °C and the second container warming to around 500 °C. The specially designed heat pump machine can be thermodynamically reversed to operate as an engine. In that case electricity is recovered by passing the heat from the hot container back through the machine to the cold container, while the machine drives an electrical generator. During the process, the containers return close to their original temperatures.

Figure 2.61 shows a schematic of Isentropic's 30 MW h PHES using gravel as the storage medium.

Isentropic claims a round trip efficiency of over 72–80 %. The cost per kW h can be kept very low because gravel is such a cheap and readily available material.

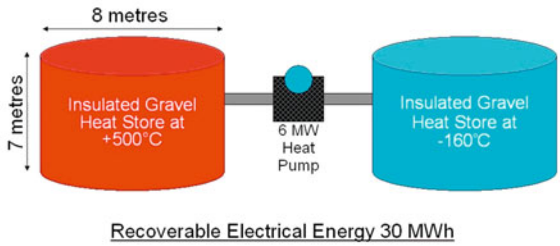


Fig. 2.62 Isentropic's pumped heat energy storage system. *Source* http://www.isentropic.co.uk/our-phes-technology. Accessed February 2013

Additionally, the system is not constrained by geology unlike pumped hydro energy storage systems. It is modular, scalable and environmentally benign (Fig. 2.62).

2.6 PAWA: *Abulecentric* Power Supply System

PAWA, an acronym for Providing Alternative Watts for All, is an international initiative to develop community power supply for developing countries. The fundamental architecture of PAWA was developed by this author. The focus of the first implementation of PAWA is sub-Saharan Africa. The pioneering effort is PAWA 774[9] which is being implemented for the 774 local government areas (LGAs) of Nigeria. PAWA 774 is a private sector-led initiative to deploy 10 MW of clean, renewable energy power plants to each of the 774 LGAs in Nigeria. The combined capacity for the whole country will be almost 8 GW (i.e., 8,000 MW) of clean, eco-friendly electricity, built in clusters of 100 KW units. A local, smart micro-grid mesh interconnects the units thereby providing adequate power to the entire nation, one community at a time (Fig. 2.63).

PAWA 774 is a unique power generation and distribution model and the first of its kind in Africa. With the ubiquitous installation of community energy storage appliances, PAWA 774 aims to serve the right amount of power to each community. The generated power is deployed as required, taking individual electrical energy needs into account.

PAWA 774 is built on the generation of eco-friendly electrical power, from abundant, renewable energy sources such as solar, wind, rivers and bio-mass. The reliance on fossil fuels to generate power is reduced by tapping into energy sources that are cheaper and cleaner to harness and produce. When completed, nearly one million jobs would have been created in the vibrant clean energy sector. Moreover, the initiative is expected to attract support from corporations, small businesses and local communities since the development of the power plants will be beneficial to both industry and residential life in the LGAs. PAWA 774 has four main goals for benchmarking the success of the initiative:

[9] Source: www.pawa774.com. Accessed January 2013.

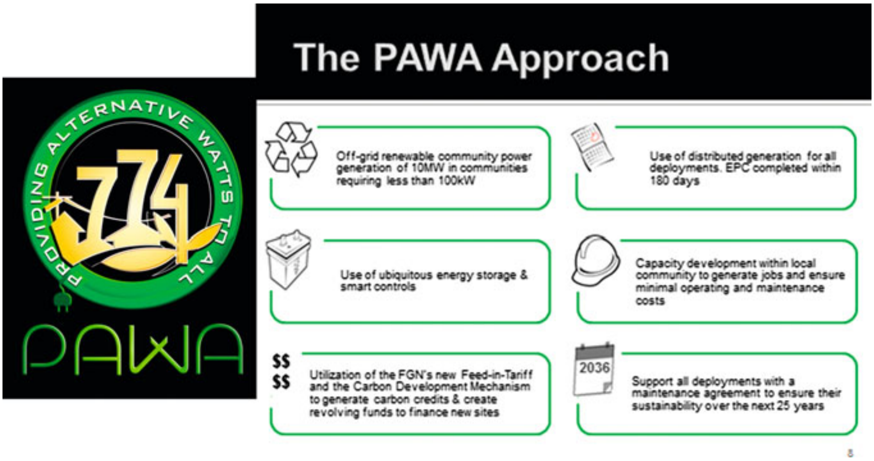


Fig. 2.63 *Abulecentric* clean and renewable power generation and distribution system

1. **Power**—A renewable power plant (minimum 10MW rated capacity) will be built and operated in each LGA. When the project is completed, the combined 8,000 MW will be the distributed power available throughout all the 774 LGAs of Nigeria.
2. **Jobs**—Nigerians will be trained and an average of 1,200 clean energy jobs will be created in each LGA. High priority is placed on the recruitment of indigenes and residents of the local community.
3. **Economy**—Community power companies are created under a franchise business initiative in each LGA. Each franchised company will seek the active involvement of the community by ensuring that local entrepreneurs and investors are equity holders in the company.
4. **Corporate Social Responsibility** (**CSR**)—Private corporations "adopt communities" by providing direct CSR funding to build the renewable power plants for communities of their choosing.

The Bank of Industry (OPARA 2012) is one of the financial institutions supporting PAWA 774 to develop the distributed renewable energy system in Nigeria. Business loans at favorable interest rates will be provided to cover the capital costs of the power plant installation. The PAWA 774 initiative fulfills all the tenets of *abulecentrism*. It is private-sector led. Local entrepreneurs are promoted as key stakeholders and operators. The power implementation is community focused and highly scalable. There is massive capacity development. Local indigenes are involved as trainees and business owners. The fuel for the power generators is derived from renewable energy sources. The entire power system can easily be adapted to local climate, available manpower, and socio-economic conditions.

2.7 South Africa's Clean Power Initiatives

South Africa has committed to the use of renewable energy sources in meeting the bulk of the nation's power needs. By the year 2030, the country plans (REVE 2012) to have a built up capacity of 8,400 MW for solar power and 8,400 MW for wind power. The 5,000 MW solar park planned for Upington (a town in the Northern Cape province of South Africa) is more than the entire 4,200 MW power generated (2013) in Nigeria. A 50 MW concentrated solar power plant is under development for Touwsrivier, a small railway town in the Western Cape of South Africa.

According to South Africa's Department of Energy (Department of Energy, 2013):

> A pilot programme has been launched to establish a limited number of public–private sector institutions in conjunction with the relevant municipalities to provide electricity services on an integrated basis. The service-provider will own and maintain the systems, allowing longer-term financing to ameliorate monthly payments. It will provide the service against a monthly fee.

This is an example of *abulecentric* power development at its best.

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