Compendium of Best Practices of Renewable Energy

GREEN PRODUCTIVITY

ASIAN PRODUCTIVITY ORGANIZATION

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Foreword

Renewable energy is not a new concept. Historically, wood, one type of biomass and renewable energy source, supplied up to 90% of human energy needs. However, as the use of fossil fuels such as coal, petroleum, and natural gas increased, we became less reliant on biomass as an energy source. The excessive use of fossil fuels, however, has resulted in increased greenhouse gas emissions and thereby contributed to climate change with its many adverse effects. If we continue to use fossil fuels at the same rate, greenhouse gas emissions will inevitably increase. A widely accepted climate model predicts that the average temperature on the earth's surface could increase by 3-7º F above 1990 levels by the end of this century, causing irreversible changes in the atmosphere, putting human and animal health at risk, and wreaking havoc on ecosystems.

To mitigate the adverse effects of climate change and ensure energy security, we are once again looking to renewable energy sources to find better ways to meet our energy needs. Fortunately, there are effective alternatives to fossil fuels based on unlimited energy sources such as wind, solar, geothermal, and ocean and hydro power. All can help reduce our dependence on nonrenewable sources, meet energy requirements, and reduce carbon dioxide and other greenhouse gas emissions. These renewable forms are clean sources of energy which have a much lower environmental impact than conventional fossil fuels. At the same time, these substitute energy forms can also contribute to national or regional economic development, for example, by expanding business and employment opportunities in renewable energy industries.

Renewable energy use has been receiving increasing attention worldwide, including in Asian Productivity Organization (APO) member countries, along with national energy security and environmental concerns. To address the need to find new ways of using renewable energy sources, the APO organized a seminar on Technology Innovation in Renewable Energy in 2009 and an observational study mission on Energy Efficiency and Renewable Energy to California, USA, in 2010. Best Practices of Renewable Energy was compiled based on the feedback received from those projects and needs expressed by stakeholders. It is hoped that this compendium will be useful to renewable energy practitioners and professionals while promoting general awareness of potential sources of renewable energy and how they can be utilized most productively in the Asia-Pacific region.

Ryuichiro Yamazaki
Secretary-General

Tokyo
December 2011

Overview

Best practices in energy efficiency will let us consider ways to save money, provide economic benefit for people living in different countries, reduce risks of high energy costs in the future, and help us to comply with global climate changes and improve our environmental standards.

This report documents some of the world's best practices in using renewable energy sources, taking into consideration the application of these practices to Asian countries. Through report reviews, expert consultations, web research and telephone interviews, the author surveyed numerous individual, communal and public practices on renewable energy (RE).

The best practices introduced in this publication were chosen for an in-depth look into the technological, economic, and environmental results of these RE practices. In our preliminary work, we conducted cursory research on globally-known renewable practices in each RE field.

We wish that we could have taken more time for deeper analyses on other practices, especially in the cases of developing countries. Further study based on a detailed scoreboard will provide more digestible best practices and models in the world. We expect that the many best practices introduced in this report will have good content in RE that others can learn from.

Chapter 1: Wind Energy

1.1 Introduction

Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and the rotation of the earth. Wind flow patterns are modified by the earth's terrain, its bodies of water, and vegetation. Humans use this wind flow, or motion energy, for many purposes, such as sailing, flying a kite, and even generating electricity.

Winds are variable in both time and location. Some parts of the world are exposed to frequent high winds, while others have almost no wind. Places where high and low winds occur are determined by the effects of the earth’s rotation.

Wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which then connects to a generator and makes electricity. We can look inside a wind turbine to see the various parts and view the wind turbine animation to see how a wind turbine works. (http://www1.eere.energy.gov/windandhydro/wind_how.html)

Many economies have recently been working on improving the performance, lowering costs, and accelerating the deployment of innovative wind power technologies. Greater use of abundant wind resources for electric power generation will help stabilize energy costs, enhance energy security, and improve the state of our environment.
(http://www.windandwater.energy.gov/)

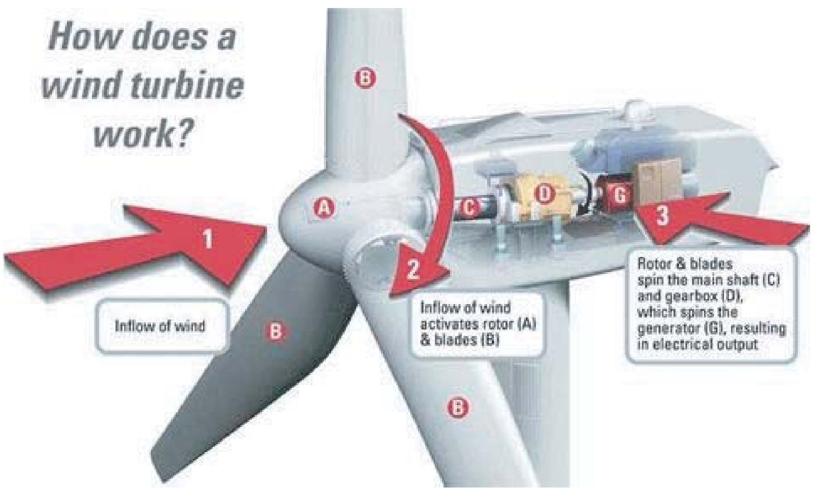


Figure 1. Mechanism of wind turbine (source: Atlantis Solar)

Like old-fashioned windmills, today’s wind machines use blades to collect the wind’s kinetic energy. The blades are connected to a drive shaft that turns an electric generator to produce electricity.

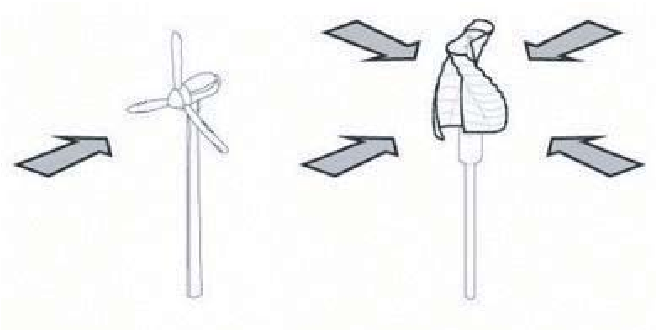


Figure 2. Types of wind machines (source: Helix Wind)

Wind machines used today are grouped into two types, based on the direction of the rotating shaft (axis): horizontal axis wind machines and vertical-axis wind machines. There are various sizes of wind machines. The capacity of small turbines used to power a single home or business is less than 100 kW. Some large commercial-sized turbines have a capacity of five MW. Larger turbines are often divided into wind farms that provide electricity to the electrical grid (EIA Energy Kids).

USA

At the end of 2009, the installed capacity of wind power in the USA was just over 35 GW, making it the world leader ahead of Germany. Wind power accounts for about 1.9% of the electricity generated in the USA. These new installations place the country on a trajectory to generate 20% of the nation's electricity from wind energy by 2030. Wind power is now one of the leading sources of new power generation in the country, along with natural gas.

Germany

Until 2007, Germany was the world's largest user of wind power, with an installed capacity of 22.3 GW. In 2009, the installed capacity was 25 GW, below the 31 GW that had then been installed in the USA. Offshore wind energy also has great potential in Germany. Wind speed at sea is 70 to 100% higher than onshore, and much more constant. A new generation of five MW or larger wind turbines capable of making full use of the potential of wind power at sea has already been developed, and prototypes have become available.

China

At the end of 2009, wind power in China accounted for 25.1 GW of its electricity generating capacity. China is the third-largest producer of wind power, after the USA and Germany. With its large land mass and long coastline, China has exceptional wind resources.

Around 15 Chinese companies are producing wind turbines commercially, and several dozen more are making components. Turbine sizes of 1.5 to three MW have become common. Leading wind power companies are Goldwind, Dongfang Electric, and Sinovel. In 2008, China also increased its production of small-scale wind turbines to about 80 MW.

1.2 Best Practices: Wind Energy

Axis of rotation direction: Horizontal Axis Wind Turbines (HAWT)

The Roscoe Wind Farm in Roscoe, USA

Location	Texas, USA
Size of land	100,000 acres (the world's largest wind farm, approximately 405,000,000㎡)
Capacity of facility	781.5 MW
Generator	627 wind turbines
Power usage	250,000 average Texan homes

source: Altergyshift

Hanil Farm, Daegwanryeong Farm, Samyang Ranch, ROK

Location	PyeongChang-gun, Gangwon-do, ROK
Size of land	166,11㎡
Annual power generation	244,400 MWh
Generator	2MWh 49 units
Central height	80m

source: The Hankyoreh

Yeongdeok-gun Wind Farm, ROK

Location	San #24, Changpo-ri, Yeongduk-gun, Gyeongsangbuk-do, ROK
Size of land	166,117㎡
Capacity of facility	39.6 MW
Annual power generation	96,680 MWh (electricity usage by about 20,000 households)
Generator	1,650 kWh, 24units
Central height	80m

source: Youngduk Wind Power Co., Ltd

Huitengxile Wind Farm, China

Mode	onshore electricity
Country	China
State	Inner Mongolia Autonomous Region
City	Wulanchabu City
Project development	Inner Mongolia Long Yuan Wind Power Development Co. Ltd,
Installed capacity	100.25 MW
Annual power generation	130 million kWh
Manufacturer	GE Energy
Operator	Huitengxile Power Plant

source: Wikimedia Commons

Axis of rotation direction: Vertical Axis Wind Turbines (VAWT)

VAWT installed at a restaurant, UK

Location	Promenade Restaurant, Cleveleys, UK
Generator	five ground-mounted turbines
Physical dimensions	5m high x 3.1m in diameter
Operation mode	Max wind speed: 16m/s;
Installation	min. wind speed: 4.5m/s
date	March 2009

source: Ingenia

Offshore wind energy

Arklow Bank Offshore Wind Park, Ireland

Location	Arklow Bank, Ireland Offshore Wind Farm, located about 10 kilometers off the coast of Arklow, Ireland
Footprint	600m^2
Wind turbines	seven GE wind energy 3.6s offshore
Generator	1,600 households
Capacity of facility	25 MW
Turbine height	124m
Description	The world's first commercial application of offshore wind turbines over three megawatts in size, and Ireland's first offshore wind facility.

source: GE Energy

Thornton Bank Wind Farm, Belgium

Location	North Sea, 30 km off the coast of Zeebrugge, Belgium
Total investment	€153 million (Phase One)
Capacity	30 MW (six turbines × five MW)
Manufacturer	REpower Systems
Operator	C-Power
Generator	600,000 people (expected)

source: LM Wind Power

Kemi Ajos Harbour Wind Farm, Finland

Location	Ajos, Kemi Harbour, Finland
Total investment	€50 million
Capacity	30 MW
Manufacturer	WinWin D, ABB
Operator	PVO-Innopower Oy
Description	The first stage of this 30MW project in northern Finland consisted of the construction of five 3-MW turbines, two onshore and three on artificial islands
Annual power Generation	8,000 MWh

source: WinWinD

Chapter 2: Bioenergy

2.1 Introduction

Biomass is basically a stored source of solar energy initially collected by plants during the process of photosynthesis, whereby carbon dioxide is captured and converted to plant materials, mainly in the form of cellulose, hemi-cellulose and lignin (IEA, 2007).

Biomass is a source of fuel for heat and power derived from living organisms. It covers a range of organic materials produced from plants and animals that feed on the plants. Biomass includes crop residues, forest and wood process residues, animal waste including human sewage, municipal solid waste, food processing waste, purpose-grown energy crops, and short rotation forests.

Biomass can be divided into four groups: wood residues, agricultural residues (from crops, food processing and animals), dedicated energy crops, and municipal solid waste (Easterly & Burnham 1996; Demirbas et al., 2009; Evans et al., 2010).

Wood residues are generated by the wood products industry, including paper mills, sawmills, and furniture manufacturing. Urban wood waste and forestry residues are important sources of wood residues.

Agricultural residues are basically biomass materials that are byproducts of agriculture. This includes cotton stalks, wheat and rice straw, coconut shells, maize and jowar cobs, jute sticks, rice husks, etc.

Dedicated energy crops include short-rotation woody crops and herbaceous crops. Short rotation energy crops are poplar, willow, eucalyptus and non-woody perennial grasses such as miscanthus. Crop rotation periods are usually 3-10 years for woody crops such as willow and poplar. Municipal solid waste includes paper, other organics, glass, plastic, etc.

Among the various sources of renewable energy, biomass is one of the few in which availability does not depend on weather or seasonal conditions and can be stored for use on demand. Furthermore, biomass is regarded as carbon-neutral because when it is used in combustion in place of fossil fuels, a net reduction in carbon emissions is achieved.

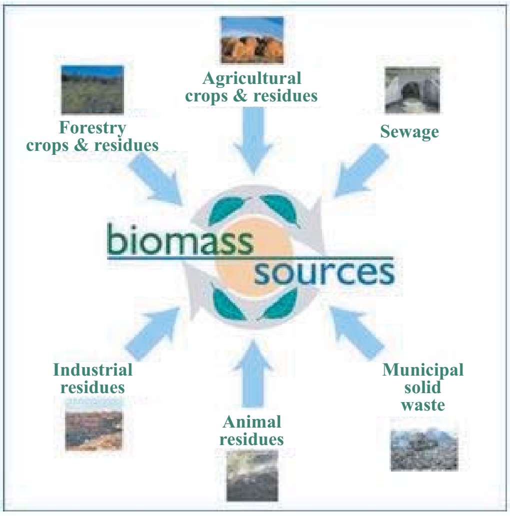


Figure 3. Biomass sources (source: Plantoverhaul)

There are currently three basic categories of biomass plants, as Figure 4:

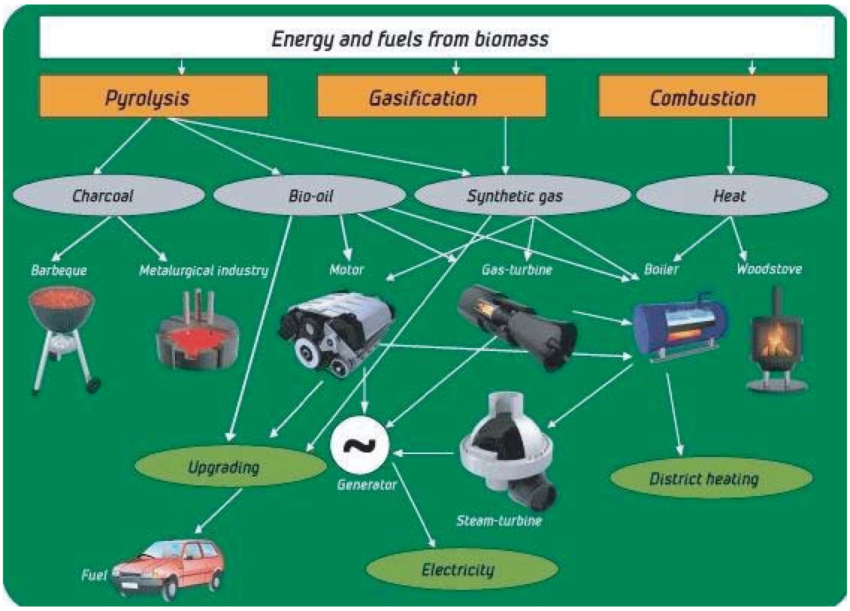


Figure 4. Three basic categories of biomass plants (source: Northern Ireland Planning Service)

Biological Process

Anaerobic Digestion (AD)

AD is a method of waste treatment that produces a gas with high methane content from organic materials such as agricultural, household and industrial residues and sewage sludge (feedstock). The methane gas can be used to produce heat, electricity, or a combination of the two. Energy from AD is also effectively carbon-neutral in that the carbon it releases is approximately equal to the carbon absorbed from the atmosphere by the plants which constitute the origin of the organic waste.

Sewage Gas

Sewage sludge differs from farm waste in that it generally has a far higher inert content (more than 40% of the dry solid matter in sewage is usually ash). However, as it is only the organic matter that is digested, the gas produced from sewage is of a similar composition to that derived from farm waste, and the main difference in the digestion plant is one of scale. As sewage waste treatment is generally more centralized, sewage sludge digesters are usually much larger than farm waste digesters.

Organic waste materials such as food, paper, and garden waste decompose in landfills to produce landfill gas (LFG), a mixture of methane, carbon dioxide, and a wide range of minor components. The use of LFG provides energy from a source which would otherwise be flared off or vented to the atmosphere and thus wasted.

The main difference between landfill gas systems and other forms of anaerobic digestion is that the landfill itself is effectively the digester so there are no tanks constructed for this purpose. However, the generation plant used to extract the gas is broadly similar to that employed for other forms of anaerobic digestion.

2.2 Best Practices: Bioenergy

Blaabjerg Biogas Plant, Denmark

Location	Blaabjerg Biogas Plant, Denmark
Size of land	166,117m^2
Animal manure	222 tons/day
Alternative biomass	87 tons/day
Biogas production	3.1 millionm^3/year
Digester capacity (2×2500 m3)	5000m^3
Process temperature	53.5°C
Utilization of biogas	CHP plant
Investment cost	DKK44.1 million
Operation startup	1996

source: BWSC

Blaabjerg Biogas Plant, Denmark

Location	Goblin Combe Environment Centre, Plunder Street, Cleeve, Bristol
Capacity	50 kW
Buildings served	Residential accommodation
Resource	Wood chip
Purpose	Hot water and underfloor heating
Wood chip storage	50m^3
Total annual energy usage	About 60,000 kWh
Operation startup	2007

source: Goblin Combe Environment Centre

Bioenergy Village Juhnde, Germany

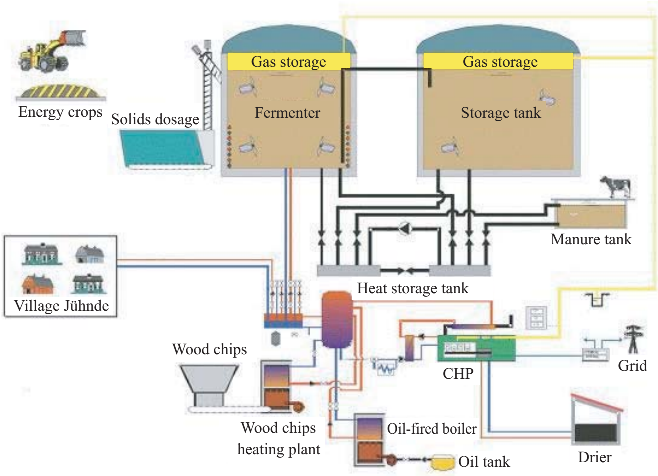


Figure 5. Schematic of the bioenergy plant Jühnde (source: IEA Bioenergy Task 37)

Location	Gottingen, Germany
Size of land	166,11m^2
Capacity of facility	39.6 MW
Digester volume	3,000m^3
Liquid manure	9,000m^3/year
Energy crops	15,000 tons/year
Wood chip boiler	550 kWth
Wood chips	350 tons/year
Peak load oil boiler	1,600 kWth
Storage tank	4,400m^3
CHP	700 kW electric power, 750 kW thermal power
Total heat production	6,500 MWh/year
Total electricity production	5,000 MWh/year

source: IEA Bioenergy Task 37

Beijing Deqingyuan chicken farm biogas plant, China

Source	Agricultural waste
Country	State Beijing City, China
City	YanQing District, 50km north of Beijing
Total investment	USD6.5 million
Capacity	2.4 MW
Annual power generation	14,600 MWh
Manufacturer	GE Energy
Operator	DQY Ecological Farm
Summary	The Beijing Deqingyuan Chicken Farm Waste Utilization plant is designed to help reduce suburban electricity shortages.

source: IFC

Biogas Plant in Kuzumaki Waste District, Japan

Location	Kuzumaki, Japan
Capacity of facility	37 kW
Summary	- Electricity is generated from cow dung - Biomass facilities - Wood chips are converted to gas - Bark is made into pellets for fueling stoves - The town has a biomass facility, uses wood chips from larch trees to create gas, and bark to make pellets for heating stoves.

source: Tonymcnicol

Ökostrom Mureck (biogas) in Murekeu, Austria

Location	Murekeu, Austria
Capacity of facility	8400 MW
Temporary silo	600m^3 Driving silo: 6000m^3
Mixing pit	100m^3 Hydrolysis tank: 200m^3
Anaerobic methane fermentation reactors	4x1000m^3, each equipped with a 300m^3 gas-reservoir
Storage tank for separation of solids Substratum repository (biogas manure storage tanks)	- 2 x 3600m^3 in Mureck - 1 x 1300m^3 in Wittmansdorf - 1 x 700m^3 in Gosdorf - 1 x 5300m^3 in Weitersfeld

source: Fedarene

Bioplin Kolar Marjan - Biogas Plant, Slovenia

Source	Agricultural waste
Country	Pomurska Regija , Slovenia
City	Logarovci
Total investment	€5.2 million
Capacity	1 MW
Annual power generation	Eight million kWh
Operator	Marjan Kolar
Summary	The thermal energy produced by the plant is used for heating the digesters, pig farm, and grain drying room.

source: Energyblueprint

Methane capture & power generation in a distillery, India

Mode	Cogeneration
Country	India
State	Andhra Pradesh
City	Village Sankili
Project development	GMR Industries Ltd., Hyderabad
Total investment	Rs.13.50/- Crores (USD3.38million)
Production cost	Rs.one (USD0.25) per Unit.
Installed capacity	0.96 kW
Annual power generation	710,137 kWh
Grid	Off-grid
Manufacturer	Enviro Tech., Nagpur, India
Operator	GMR Industries Ltd.

source: Energyblueprint

Steven's Croft Biomass Station, UK

Source	Woodchips
Technology	Biomass
Country	Scotland, UK
City	Lockerbie
Total investment	€132 million
Capacity	44 MW
Generator	70,000 households
Manufacturer	Siemens, Kvaerner Power, Nexans
Operator	E.ON Climate and Renewables

source: Moss MacDonald

CAMBI Anaerobic Digestion Process, Norway

Location	Verdal Municipality, North of Trondheim, Norway
Capacity	Organic waste ABP Cat. II & III + sludge (50/50) 50,000 t/a Biogas 29,6 GWh Existing landfill gas 5,7 GWh Electricity prod 13,8 GWh Fertilizer after dewatering 15,400 t/a
Materials	Source-separated household waste (food waste), organic industrial waste (from food processing industries), sewage sludge, fish waste and animal byproducts category II and III (slaughterhouse waste)
Summary	The biogas plant is designed and built by CAMBI. The Norwegian company has one of the world's most sophisticated Anaerobic Digestion processes.


source: CAMBI

LFG (Landfill Gas), ROK

Source	Landfill Gas
Organization	Daegu City Gas Co., Ltd.
Country	ROK
Location	Daegu
Total investment	KRW25 billion since 2006
Summary	The Bangcheon-ri Landfill Gas-to-Energy project was registered to the UN Climate Change Convention (UNFCCC) as a CDM business. 225,919 tons of CERs may help provide around €3 million from carbon emission reduction activities (Daegu Metropolitan City, 2010).

source: KOREA.Net

Chapter 3: Waste Energy

3.1 Introduction

Energy-from-waste (EFW) facilities produce clean, renewable energy through the combustion of municipal solid waste in specially designed power plants. These plants are equipped with the most modern pollution control equipment available for cleaning emissions. (source: http://www.gcsusa.com/faq.htm)

In many countries, energy derived from waste is considered a renewable energy, by virtue of the sustainable and indigenous nature of the municipal solid waste stream that fuels these power plants. Moreover, unlike other renewable sources that only produce power, the creation of energy from waste means that waste disposal services are provided for communities around the world. (source: http://bantrel.com/markets/renewableenergy.aspx)

EFW facilities serve as a way to dispose of trash, and they are an alternative to land disposal systems that release methane, a potent greenhouse gas, as trash decomposes. Waste-to-energy facilities also produce electricity, lessening our reliance on fossil fuel power plants that release CO_2 emissions into the atmosphere when coal or oil is burned. The operation of waste-to-energy plants allow us to avoid the release of methane that would otherwise be emitted when trash decomposes, and the release of CO_2 that would be emitted by generating electricity from fossil fuels.
(source : http://www.integraglobalventures.com/EnergyFAQ.aspx)

There are various types of waste-to-energy technologies, including pyrolysis, gasification, combustion, esterification, fermentation, and anaerobic digestion. Some of these waste-to-energy technologies use chemical or biochemical processing, while others use thermal processing. Municipal waste-to-energy technology can meet household energy needs, while biofuels created from waste can be used to power automobiles.
(source: http://www.bionomicfuel.com/cost-effective-waste-to-energy-technologies/)

This section relates to the thermal process which uses a high temperature process to release the chemical energy in the fuel.

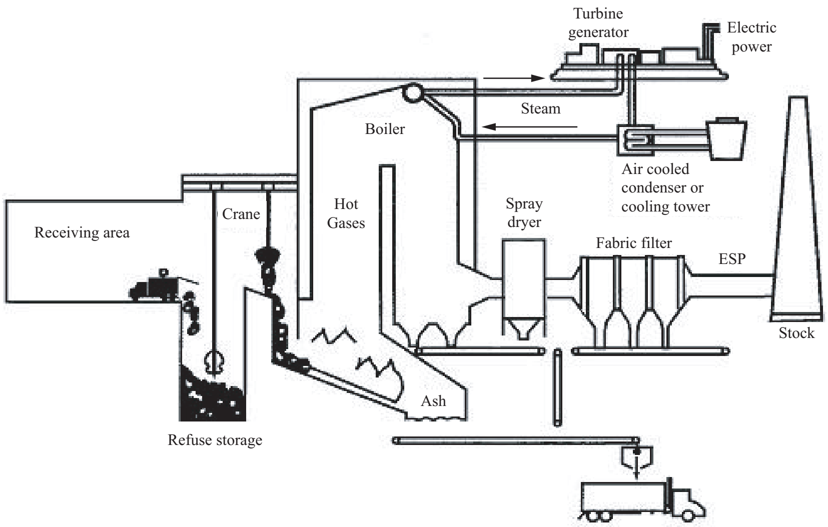
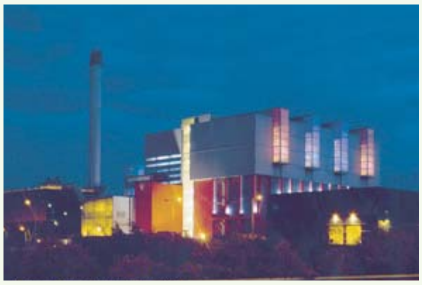


Figure 6. Schematic of Waste-to-Energy Plant (source: KAB)

3.2 Best Practices: Waste Energy

Tyseley Waste Energy Plant, UK

Source	Rubbish Waste
Technology	Waste energy
Country	UK
City	Birmingham
Total investment	€132 million
Capacity	35,000 tons of waste annually
Generator	40,000 local homes
Manufacturer	Veolia Environmental Services Birmingham Ltd.



source: Industcards

Spittelau District Heating Plant, Austria

Source	Waste gas
Technology	Waste energy (district heating)
Country	Austria
City	Vienna
Total investment	€132 million
Capacity	36,400 MW annually
Generator	190,000 homes, 4,200 public buildings

source: Wikimedia Commons

Chapter 4: Small Hydro

4.1 Introduction

Small hydro power (SHP) transforms the potential energy of water, mainly high pressure, into mechanical shaft power which is finally converted to electricity (Papantonis, 2001; Fritz, 1984). Small hydro power utilizes local water resources without the need for extended infrastructure facilities and huge dam constructions, making considerably less impact on the environment.

Although there is no internationally agreed definition of the size of an SHP plant, the rated power of an SHP is usually less than 10 MW, while all stations with power rated at less than one MW are regarded as *min*" (IHA, 2000). For very small applications whose rated power is less than 50 KW, one may also use the term *micro-hydropower*.

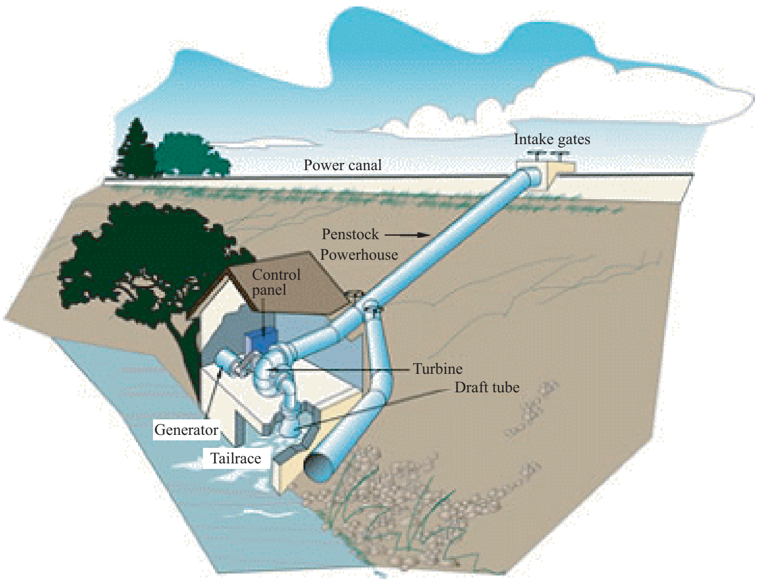


Figure 7. Schematic of Small Hydro Power (source: Renergeia)

Taking into account that the most appropriate locations for installations of large hydropower stations have already been exploited, as well as the fact that local communities point out environmental impact and voice strong opposition against new hydropower stations, SHP stations remain an attractive opportunity for further utilization of available hydro potential (Kaldellis, 2007). SHP has relatively low environmental impact compared to large hydro, because small hydro projects usually have minimal reservoirs and require little civil construction work.

SHP is a renewable energy that can be connected to a conventional electrical grid at low cost, or built in isolated areas that would be uneconomical to serve from the grid, or otherwise, in areas where there are no national electrical distribution networks. Small hydro projects are seen as making relatively low impact on the environment compared to large hydro.

4.2 Best Practices: Small Hydro

Kamataka Hydro Power, India

Project location	Karnataka, India
Project proponent	Sandur Power Company, Ltd
Credit type	Voluntary Carbon Standard VERs
Total emission reductions	127,000 tons of CO2e between 2005 and 2007
Additionality test	Established using the CDM additionality tool. The project is not the least-cost option for local power generation; coal would be the more economical choice for power buyers in the absence of carbon finance. Furthermore, the project is not one of common practice - the developer is one of the few local independent power producers that together supply just two percent of the electricity in the regional grid.


source: Karnataka Renewable Energy Development Limited

Dangjin Small Hydro Power, ROK

Country	ROK
Location	Dangjin
Annual power generation	28,000 MWh
Manufacturer	Korea East-West Power Co.

source: Hankyung

Guizhou Hydro Power, China

Project location	Guizhou Province, China
Project proponent	Guizhou Zhongshui Hengyuan Project Management and Consulting Co., Ltd.
Credit type	Voluntary Carbon Standard VERs
Total emission reductions	8,200 tons of CO2e between 2006 and 2008
Additionality test	Established using the CDM additionality tool. The benchmark financial internal rate of return (FIRR) on total investment for hydro power projects is 10%. Without the income from carbon credits, the FIRR of the project is 6.39% and is financially unacceptable. With the income from carbon credits, the FIRR is increased to 11.75%.368 Gcal/yr (1.6%)

source: Carbon-clear

Ghazi Barotha Hydroelectric Project, Pakistan

Country	Pakistan
State	City Indus River, 100km from Islamabad
Project development	Pakistan Hydro Consultants, a joint venture between Harza
Engineering company	Ewbank Preece and Binnie, Black & Veatch, Nespak, and Associated Consulting Engineers
Total investment	USD2.3 billion
Production cost	Feed-in tarif
Installed capacity	1,450 MW
Annual power generation	6,600 million kWh
Manufacturer	Impregilo, Saadullah Khan & Brothers, Nazir & Company, Voith, Austrian VA Tech Voest, Dongfang Electric Corporation
Operator	Water and Power Development Authority (WAPDA)

source: Mott MacDonald

Khudi Hydropower Project, Nepal

Country	Nepal
State	Lamjung District
City	Khudi
Project development	Butwal Power Company, SCPHI of Canada, Lamjung Electricity Development Company (LEDCO)
Total investment	NPR570 million (Nepalese Rupee)
Installed capacity	4 MW
Annual power generation	24,000,000 kWh
Manufacturer	Himal Hydro & General Construction Ltd.
Operator	Khudi Hydro Power Ltd.

source: HydroWorld

Chapter 5: Active Solar - Photovoltaic

5.1 Introduction

Active solar technology can be divided into two categories: Photovoltaic (PV) and Solar Water Heating (SWH). PV is unique among renewable energy technologies in that in addition to generating electricity from daylight, it can also be used as a building material in its own right. PV can either be roof-mounted or free-standing in modular form, or integrated into the roof or facades of buildings through the use of solar shingles, solar slates, solar glass laminates and other solar building design solutions. The most commonly available solar cells are made from high-grade silicon that is treated with negatively and positively charged semiconductors, phosphorous and boron.

Solar cells can be separated into the following categories, according to their crystalline structure:

a. Mono-crystalline silicon cells

b. Amorphous silicon cells

c. Dye-sensitized solar cells (DSC)

d. Poly- or multi-crystalline silicon cells

e. Other thin films

There is considerable variation in appearance, but many solar panels are dark in color and have low reflective properties. Solar panels are typically 0.5 to one square meter in size, with a peak output of 70 to 160 W. A number of modules are usually connected together in an array to produce the required output, the area of which can vary from a few square meters to several hundred square meters. A typical array on a domestic dwelling would have an area of nine to 18m^2, and would produce one to two kW in peak output.

5.2 Best Practices: Active Solar - Photovoltaic

In buildings

Sports hall, Germany

Location	Tübingen, Germany	  source: Sunways
Date of completion	October 2004	
Type of building	Sports hall	
Type of integration	Hung, rear-ventilated facade	
Type of modules/cells	Special modules, glass-film laminate / Polycrystalline	
Number of modules	970	
Installed power and area	43.7 kWp, 525m^2	

The University of Kitakyushu, Japan

Location	Kitakyushu, Japan
Size of land	17,410m^2
Form and capacity	•Polycrystalline (roof mounted) : 129.6 kW •Monocrystalline (shading device) : 23.4 kW
Power efficiency	•Polycrystalline : 13.3% •Monocrystalline : 7.2%
Amount of energy saved	368 Gcal/yr (1.6%)

source: IBEC

Balanced Energy Houses Nieuwland, Netherlands

Location	Amersfoort, Utrecht, Netherlands
PV application	Inclined roof - integrated Inclined roof - transparent roof
PV power total	21.8 kWp
Summary	•A double residence has been built in the city of Amersfoort •Annual energy consumption is fully covered by the solar system •The houses are low-energy houses (energy performance of 0.56)

source: PV Database

Villa Garten Shin-Matsudo, Japan

Location	Matsudo, Chiba, Japan
PV application	Inclined roof - mounted
PV power total	123 kWp
Type of modules/cells	Special modules, glass-film laminate / Polycrystalline
Number of modules	970
Installed power and area	43.7kWp, 525m^2

source: IBEC

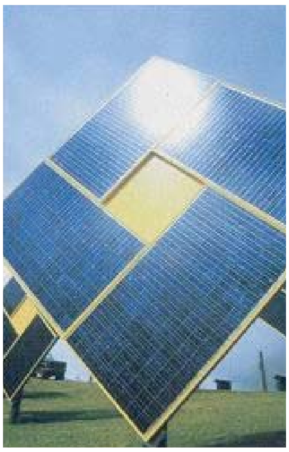
Non-building PV structures: Urban street equipment

Parking meters, information signs, ticket vending machines, information boards, etc., Spain

<table>
<tr><td>Project name</td><td>"Air trees" in the Vallecas Bioclimatic Eco-boulevard, Madrid</td><td rowspan="4">
source: PV Database</td></tr>
<tr><td>Location</td><td>Madrid, Spain</td></tr>
<tr><td>PV power total</td><td>28.8 kWp</td></tr>
<tr><td>Summary</td><td>•Bioclimatic boulevard of Vallecas is a major urban development in Madrid
•Three "urban trees" (called “Climatic”, “Ludic”, and “Media” trees) have been installed
•Bioclimatic design principles, metallic structures, vegetation and PV modules are architecturally integrated
•Annual electricity consumption is compensated by the PV system</td></tr>
</table>

solar parking meter

“Infoconcept” PV Street Information Board



PV "sunflower" integrated into the landscape Multi-oriented system

Figure 8. PV systems (source: Solar Design Associates, USA)

Non-building PV structures: Barriers

Fences, gates, noise barriers, etc., Italy, Switzerland, Germany

Location	Description	Constructed	Picture
Marano d'Isera, Italy	730 kW Noise barrier along A22 Brenner Motorway	FAR Systems 2009	
Domat/Ems, Switzerland	100 kW World's first photovoltaic noise barrier along the A13 motorway	1989	
Aschaffenburg, Germany	Solarpark Aschaffenburg, noise barrier A3	Ralos 2009	

source: PV Resources

Non-building PV structures: Shelters and kiosks

Non-building PV structures can also be installed as below:
Shelters: Bus stops, telephone boxes, parking, umbrellas, information stands, etc.
Kiosks: Pavilions, toilets, refreshments, newsstands, etc.

In transport

PV has traditionally been used for auxiliary power in space. PV is rarely used to provide motive power in transportation applications, but is being used increasingly to provide auxiliary power for boats and cars. Recent advances in solar race cars, however, have produced cars that could be used for consumer transportation with minor changes.

Project name	Solar Shuttle "RA 82"
Location	Alster River in Hamburg, Germany
Summary	•The world's largest solar boat began operation on 23 May, 2000 •27 meters long, and 34 tons in weight •Speed: up to 15 kilometers per hour •Materials: 40 tons of stainless steel and a roof composed of solar modules


source: PV Database

Chapter 6: Active Solar - Solar Water Heating

6.1 Introduction

Active solar hot water systems employ a pump to circulate the water or heat transfer fluid and a controller to turn the pump on and off, depending on the temperature of the tank and the collectors. The solar collector converts sunlight to heat a carrier fluid which the pump transports to storage tanks and the distribution system. Active systems are usually significantly more efficient than passive systems but are more complex, expensive, more difficult to install, and rely on electricity to run the pump and controller.

The most commonly used solar collector is the insulated glazed flat panel. Less expensive panels like polypropylene panels (used for swimming pools) or higher-performance panels like evacuated tube collectors are sometimes used.

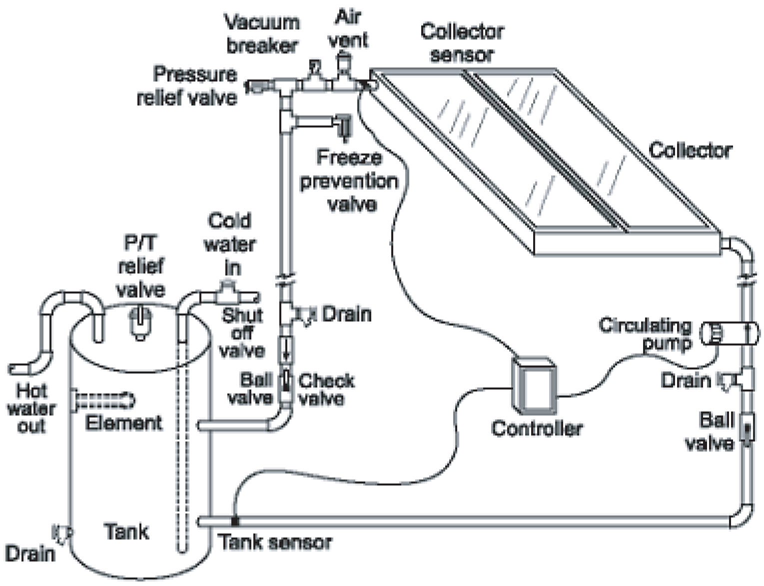


Figure 9. Active solar heating system (source: www.dnr.mo.gov)

6.2 Best Practices: Active Solar - Solar Water Heating

Installing the roof module collectors in Onsala, Sweden

Location	Onsala, Sweden	 source: Global Solar Thermal Energy Council
Heating area	220㎡	
Storage system capacity	220㎥	
Purpose	Space heating & hot water	
Heating loads	25%	
Energy saved	25 kwh/㎡	

Apartments in Saro, Sweden

Location	Saro, Sweden
Heating area	740m^2
Storage capacity	640m^3
Purpose	Space heating & hot water
Heating loads	65%
Household usage	48 households

source: ATLAS Project

Iljuk-myeon horticulture facilities, ROK

Location	Iljuk-myeon, Anseong-si, Gyeonggi-do, ROK
Heating area	218m^2
Purpose	Facility horticulture heating
Annual power generation	Solar power dependency rate: 30%
Control	Proportions of difference in temperatures
Auxiliary heat source	Firewood boiler, diesel boiler

source: ATLAS Project

Korea District Heating Corp., ROK

Location	Gyeonggi-do, ROK
Collector area	Flat-plate solar collector: 432m^2 Evacuated tubular solar collector: 637.5m^2
Purpose	District heating
Year of construction	August 2008
Annual power generation	500~600 Gcal

source: Korea District Heating Corp.

Federal Correctional Institution, USA

Location	Federal Correctional Institution, Phoenix, Arizona, USA	
Area	1,672m^2	
PV power total	28.8 kWp	
Storage system capacity	87,055ℓ/day	
Heating loads	87.1% of the water heating load	source: US DOE
Purpose	kitchens, showers, laundry, and sanitation needs	
Summary	The system includes 18,000 square feet of parabolic trough solar collectors and a 21,000-gallon thermal energy storage tank located adjacent to the solar field. An incoming cold water supply line is routed to a copper coil heat exchanger in the thermal storage tank and then sent to the buildings through insulated underground piping. The hot water is then tempered down to 140°F (60°C) when necessary and serves as preheated incoming water for the existing electric water heaters in each building. The system meets about 82% of the hot water needs for FCI-Phoenix and most of the demand during the peak morning period. It is designed to provide 4.9 billion Btu of energy per year. The electricity saved is equivalent to the amount used by 150 people for all purposes.	

Chapter 7: Solar Thermal Power

7.1 Introduction

Solar thermal electric power plants generate heat by using lenses and reflectors to concentrate the sun's energy. Because the heat can be stored, these plants are unique in their ability to generate power when it is needed, day or night, rain or shine. (source : http://www.solardev.com/SEIA-makingelec.php) People have been using solar thermal energy for thousands of years for a variety of tasks, and modern technology has considerably expanded the applications for the sun's thermal energy. This should not be confused with photovoltaics, in which the sun's light is used as a source of power to produce electrical energy. (source : http://www.wisegeek.com/what-is-solar-thermal-energy.htm)

Solar thermal power is a relatively new technology which has already shown enormous promise. With a massive resource and making little impact on the environment, it offers opportunities that are comparable to what is available in the sunniest parts of the world, similar to wind farms in European economies that have the windiest shorelines. As solar thermal power uses direct sunlight, their facilitiesmust be located in regions that have high levels of direct solar radiation. (source : http://bourhanigroup.com/SE.html)

The sun's heat can be collected in a variety of ways. Solar parabolic troughs consist of curved mirrors which form troughs that focus the sun's energy onto a pipe. A fluid is circulated through the pipes, which are used to drive a conventional generator to create electricity. Solar parabolic dish systems consist of a parabolic-shaped concentrator that reflects solar radiation onto a receiver that is mounted at the focal point at the center. The collected heat is utilized directly by a heat engine mounted on the receiver that generates electricity. Solar central receivers, or "Power Towers," consist of a tower surrounded by a large array of heliostats. Heliostats are mirrors that track the sun and reflect its rays onto the receiver, which absorbs the heat energy that is then utilized in driving a turbine electric generator. (http://www.solardev.com/SEIA-makingelec.php)

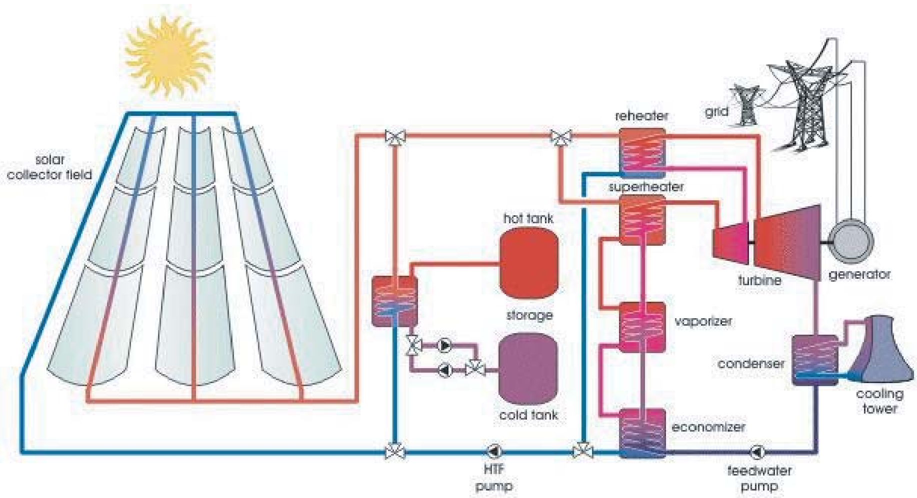


Figure 9. Schematic of Solar Thermal System (source: Volker-quaschning.de)

7.2 Best Practices: Solar Thermal Power

PS10, the world's first commercial tower plant, Spain

Location	Southern Spain
Name of project	PS10 (by Abengoa Solar)
Capacity	11 MW (24.3 GWh that will feed 5,500 households)
Project start date	1 July 2007
Heliostat (Mirror) area	75,000m^2
Tower height	115m

source: SolarPaces

Hybrid Solar Thermal Power Station, Israel

Technology	Concentrated Solar Power
Country	Israel
City	Kibbutz Samar
Capacity	170 kW
Generator	70 households
Manufacturer	AORA
Operator	AORA
Summary	Each of the station's mirrors reflects its rays towards the top of a 30 meter-high tower that houses a special solar receiver along with a 100-kilowatt gas turbine.

source: Inhabitat

Chapter 8: Geothermal Energy

8.1 Introduction

Geothermal energy technology uses the heat stored in the earth's crust, within rocks and fluids. Geothermal resources are the hot water derived from shallow ground to the hot water and rock several miles beneath the earth's surface, as well as from the extremely high-temperature molten rock called magma farther down the earth's interior. Geothermal resources can be converted into heat and electricity. There are three main technology categories: direct use applications, geothermal heat pumps, and power plants.

Direct use applications

Direct use of geothermal energy refers to the immediate use of the heat energy of hot water derived from near the earth's surface, rather than its conversion to other forms such as electricity. The major areas of direct utilization are (1) swimming, bathing and balneology; (2) space heating and cooling, including district heating; (3) agriculture applications; (4) aquaculture applications; (5) industrial processes, and (6) heat pumps (Lund, 1997).

Geothermal heat pump system

A geothermal heat pump system is a highly efficient renewable energy technology that pumps heat from the earth at a low temperature level and emits it into the heating system at a higher temperature level (Omer, 2008). A geothermal heat pump transfers heat from the earth into a building during the winter, and transfers heat out of the building during the summer. The temperature of geothermal heat is usually between 10-16℃ and warmer than the air above it in the winter and cooler than the air in the summer.

Geothermal power plants

Geothermal power plants generate electricity by using high-temperature geothermal resources that are above 150℃. There are three major types of geothermal power plants: dry-steam plants, flash-steam plants, and binary cycle plants where binary and combined slash/binary plants are relatively new designs (Yari, 2010).

8.2 Best Practices: Geothermal Energy

Direct use

In the Midland School District (South Dakota, USA), geothermal water has heated Midland Elementary and Midland High School for over 30 years. The school district pays about USD10,000 a year for phone, light, and electricity.

Location	Midland, South Dakota, USA
Floor space	2,800m^2
High pressure line	Uses 5.0 L/s and provides a 4oC
Low pressure line	Uses 0.2 L/s and
Peak power	provides a 14℃ at maximum use
Annual	0.1 MW
Use	0.24 GWh
Annual savings	USD15,000

Geothermal Heat Pump Systems

Production hall in Düsseldorf, Germany

Location	Düsseldorf, Germany
Building type	Commercial building, tertiary sector (Industry area)
Year of construction	2006
Heat source/sink	Brine/Water
Purpose	Heating, cooling & hot water
Capacity	Heating : 135.2 kW
Heat source system	Borehole heat exchanger (vertical)

source: Ground Med

New housing estate’t Rieshout in Zetten, Netherlands

Location	Zetten, Netherlands
Building type	Semidetached houses
Year of construction	2004
Heat source/sink	Brine/Water
Purpose	Heating and cooling, and hot water
Capacity	Heating : six to eight kW
	Cooling : 4.5-5.5 kW
Heat source system	Borehole heat exchanger (vertical)

source: Ground Med

Multifamily residence in Naestved, France

Location	Les Mureaux, France	 
Building type	Office building	
Year of construction	2005	
Heat source/sink	Water/Water	
Purpose	Heating and cooling	
Capacity	290 kW	
Heat source system	Aquifer/wells (open loop system)	
Summary	This building is the city hall of Les Mureaux, in the suburbs of Paris. It has an area of around 4.500m². The heating demand is fulfilled by a water-to-water heat pump of 290 kW. The cooling demand is fulfilled by free-cooling, through direct use of the water from the ground.	source: Ground Med

Multifamily residence in Naestved, Denmark

Location	Naestved, Denmark	
Building type	Multifamily residence	
Year of construction	2006	
Heat source/sink	Brine/Water	
Purpose	Heating only	
Capacity	25 kW	
Heat source system	Ground heat collector (horizontal)	source: Ground Reach

Geothermal power plant

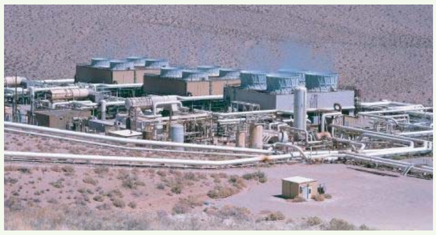
Olkaria III Geothermal Power Project, Kenya

Mode	Cogeneration
Country	Kenya
City	Naivasha - 85 miles/140 km from Nairobi
Total investment	USD150 million
Project development	Ormat Technologies, Inc.
Installed capacity	48 MW
Annual power generation	400 million kWh
Grid	Grid-connected
Manufacturer	Ormat Technologies, Inc.
Description	The first privately funded and developed geothermal project in Kenya, Africa, the second phase of construction at the Olkaria III geothermal power plant was completed in December 2008

source: EAIF

Geothermal power plants at the Coso Geothermal Field, USA

Location	California, USA
Building type	Power plant
Year of construction	1990
Heat source/sink	Hot water
Purpose	Electricity generation
Capacity	270 MW



source: Monastero et al. (2002)

Geothermal power plant in Washoe, USA

Location	Washoe County, USA
Project development	Ormat Technologies
Year of construction	1988
Project development	Ormat Technologies, Inc.
Capacity	270 MW
Manufacturer	Ormat Technologies, Inc.
Description	The extensive Steamboat Springs geothermal area contains three geothermal power-generating plants. The plants provide approximately 30% of the total Nevada geothermal power output.

source: US DOE

Chapter 9: Fuel Cell Power

9.1 Introduction

Fuel cell power systems produce clean electricity at local sites with high efficiency and use an electrochemical process, not combustion, to convert fuel energy to electricity. Fuel cells are proposed as a reliable and environmentally-friendly energy source to supply remote electricity for buildings and communication facilities, providing power through distributed generation in grid-connected applications as either primary or backup power, powering electric vehicles, and for small electronic devices such as laptop computers and cell phones (Lipman et al., 2004).

Fuel cells can be used to contribute to a significant reduction in greenhouse gases and local pollution, since they emit only water and produce virtually no pollutant emissions. Furthermore, fuel cells convert fuel into electricity at more than twice the efficiency of internal combustion engines. In transportation, for instance, hydrogen fuel cell engines operate at an efficiency rate of up to 65% compared to 25% for petrol-driven car engines (Edwards et al., 2008).

9.2 Best Practices

There are more than 2500 fuel cell systems installed at utility power plants, office buildings, schools, hotels, hospitals, nursing homes, etc. throughout the world. They are connected to the electricity network to provide supplementary power, or are installed as a grid-independent system for onsite service in areas where conventional power networks are inaccessible.

Central Park headquarters, New York, USA

Location	New York, USA	
Total capacity	200 kW	
Fuel cell type	UTC fuel cell	
Fuel type	Natural Gas	
Purpose	Off-the-grid electricity	source: WBDG

North Babylon McDonald, New York, USA

Location	New York, USA
Total capacity	5 kW (one unit)
Fuel type	Natural Gas
Purpose	Electricity for day-to-day operations and emergency backup power

source: WBDG

Conde Nast Building, New York, USA

Location	New York, USA
Total capacity	200 kW
Fuel cell Type	UTC fuel cell
Size of units	200 kW (two units)
Fuel type	Natural gas
Purpose	Electricity for the NASDAQ sign

source: WBDG

California State University, Northridge, USA

Location	California State University Northridge Campus, USA
Total capacity	1,000 kW
Fuel cell type	MCFC
Size of units	250 kW (four units)
Fuel type	Natural gas
Startup date	February 2007

source: California State University

Palmdale Water Reclamation Plant, USA

Location	Palmdale, California, USA
Total capacity	250 kW
Fuel cell type	MCFC
Size of units	250 kW (one unit)
Fuel type	Digester gas
Startup date	November 2004

source: NFCRC

March Air Reserve Base, USA

Location	Riverside, California, USA
Total capacity	five kW
Fuel cell type	PEMFC
Size of units	five kW (one unit)
Fuel Type	Natural gas
Startup date	September 2005

source: NFCRC

Chapter 10: Ocean Energy

10.1 Tidal Power

10.1.1 Introduction

Tidal current power, also called tidal stream power, is a form of hydropower that converts the kinetic energy of the tide into usable power in the form of electricity. A huge dam (called a barrage) is built across a river estuary. These work rather like a hydroelectric scheme, except that the dam is much bigger. Tidal power uses the ebb and flow of the tides to turn a turbine and push air through a pipe, which turns a turbine. When the tide goes in and out, the water flows through tunnels in the dam.

Tidal power is not yet widely used but has potential for future electricity generation. Tides are more predictable than wind and solar energy. Tidal power is practically inexhaustible and renewable, since the earth’s tides are caused by tidal forces which are due to gravitational interaction with the Moon and Sun and the earth’s rotation. Furthermore, tides are totally predictable, so we can plan to have other power stations generating at those times when the tidal station will be out of action.

A major drawback of tidal power stations is that they can only generate power when the tide is flowing in or out - in other words, for only 10 hours each day.

10.1.2 Best Practices: Tidal Power

The East River’s tidal power, New York, USA

Location	East River, New York, USA	 source: Verdant Power
Company	Verdant Power	
Total capacity	210 kW (six turbines)	
Capacity	35 kW per turbine	
Features	The first major tidal power project in the USA Project phases: ▪ Phase 1 (2002-2006): Prototype testing ▪ Phase 2 (2006-2008): Demonstration ▪ Phase 3 (2009-2012): MW-Scale build-out	

Rance Tidal Power Plant, France

Location	The Rance River in Brittany, France	 source: Energy Resources
Company	Electricite de France	
Total capacity	240 MW (two plants)	
Construction	1966	
Feature	The world's first tidal power station The largest tidal power station in the world •Generated by 24 turbines •Supplies 0.012% of the power demand in France •Barrage is 750m long	

10.2 Ocean Wave Energy

10.2.1 Introduction

Ocean wave power is the transport of energy by ocean surface waves, and the capture of that energy to generate electricity, desalinate water, or pump water into reservoirs. Waves are generated by wind passing over the surface of the sea. Wave energy is generated directly from surface waves and extracted directly from the motion by wave power devices, or from pressure fluctuations below the surface. Waves are a powerful source of energy.

10.2.2 Best Practices: Ocean Wave Energy

Archimedes Wave Swing, UK

Location	UK
Installed capacity	250 kW
Annual generation	Prototype MWh
Grid	Grid-connected
Manufacturer	AWS Ocean Energy Ltd.
Operator	AWS Ocean Energy Ltd.

Pelamis Wave Energy Converter, Edinburgh, Scotland

Location	Edinburgh, Scotland	 source: CA.GOV
Company	Pelamis Wave Power	
Total capacity	750 kW (three units)	
Investment	£40 million	
Features	▪ One unit supplies electricity for up to 500 homes ▪ The Pelamis machine is 140m-long and 3.5m in diameter ▪ Pelamis Wave Power is currently working on three wave farm projects in Portugal, Scotland, and the UK.	

10.3. Ocean Thermal Energy Conversion (OTEC)

10.3.1 Introduction

Ocean thermal power plants use the difference in temperature between deep and shallow waters to run a heat engine. This difference contains a vast amount of solar energy, which can be used to provide renewable energy for human use.

As long as the temperature between the warmer and colder surface water differs by about 20℃, a significant amount of power can be produced. These conditions exist in tropical coastal areas, roughly between the Tropic of Capricorn and the Tropic of Cancer. To bring the cold water to the surface, ocean thermal power plants require an expensive, large-diameter intake pipe, which is submerged a mile or more into the ocean's depth.

The oceans are a vast source of renewable energy which can produce about 1013 watts of power generation. The cold ocean water can also be used to cool buildings, and desalinated water is often a byproduct.

10.3.2 Best Practices: OTEC

Ocean thermal energy conversion system in Hawaii, USA

Location	Kona coast of Hawaii, USA	 source: CA.GOV
Total capacity	210 kW	
Construction	1993	
Features	The facility still holds the world record for OTEC power generation, with turbo-generator output exceeding 25 kW and more than 100 kW of net power exported to the grid.	

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