RES
RENEWABLE ENERGY SOLUTIONS

Education and Culture DG
Lifelong Learning Programme

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Lifelong Learning Programme

Leonardo da Vinci Partnership Project

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CHAPTER 1

INRODUCTION TO ENERGY

1.1. Introduction

Energy is a difficult concept to understand because it is not a concrete object that you can see or touch. To understand what energy is, you must first understand what it does. That is, although energy isn't visible you can detect evidence of energy. Jumping, moving a wheelchair, eating, and singing all require energy. Nonliving things also use energy - a clock, vacuum cleaner, and mechanical toys all require energy to move. Work is involved whenever anything moves a distance, and energy is needed to do work. Therefore, energy is defined as the ability to do work.

In physics, energy (from the Greek ἐνέργεια - energeia, "activity, operation", from ἐνεργός - energos, "active, working") is a scalar physical quantity that describes the amount of work that can be performed by a force, an attribute of objects and systems that is subject to a conservation law. Different forms of energy include kinetic, potential, thermal, gravitational, sound, light, elastic, and electromagnetic energy.

It exists in many different forms and can be transferred from one place to another by the processes of conduction, convection and radiation. Some of the more important forms of energy include: heat energy, electromagnetic radiation, and chemical energy. Heat is defined as energy in the process of being transferred from one object to another because of the temperature difference between them. Temperature variation across space can be generated by a number of different processes. A few physical laws can describe the nature of electromagnetic radiation. One of these laws suggests that any object above the temperature of absolute zero emits radiation to its surrounding environment. Another law suggests the quantity and quality of the radiation emitted is determined by the radiating body's temperature. Chemical energy comes in many different forms. However, the most important form, as it relates to this course, is the chemical energy generated by life in various types of organic molecules through the process of photosynthesis.

1.2.1. Law of Thermodynamics

The field of thermodynamics studies the behavior of energy flow in natural systems. From this study, a number of physical laws have been established. The laws of thermodynamics describe some of the fundamental truths of thermodynamics observed in our Universe. Understanding these laws is important because many of the processes studied involve the flow of energy.

1.2.1.1. First Law of Thermodynamics

Any form of energy can be transformed into another form, but the total energy always remains the same. This principle, the conservation of energy, was first postulated in the early 19th century, and applies to any isolated system. It is known as first law of thermodynamic, an expression of the principle of conservation of energy, states that energy can be transformed (changed from one form to another), but cannot be created or destroyed. Alternatively:

"The increase in the internal energy of a system is equal to the amount of energy added by heating the system minus the amount lost as a result of the work done by the system on its surroundings."

The first law of thermodynamics is often called the Law of Conservation of Energy. This law suggests that energy can be transferred from one system to another in many forms. Also, it cannot be created or destroyed. Thus, the total amount of energy available in the Universe is constant.

1.2.1.2. Second Law of Thermodynamics

Energy cannot be transfer from a low energy level to high energy level. As a result of this fact of thermodynamics, natural processes that involve energy transfer must have one direction, and all natural processes are irreversible. This law also predicts that the entropy of an isolated system always increases with time. Entropy is the measure of the disorder or randomness of energy and matter in a system. Because of the second law of thermodynamics both energy and matter in the Universe are becoming less useful as time goes on. Perfect order in the Universe occurred the instance after the Big Bang when energy and matter and all of the forces of the Universe were unified. Now we can approach to thermal machine, that are able to convert heat in kinetic energy and so in other kinds of energies.

Each thermal machine has a reference cycle, called Carnot's cycle that bind temperature, heat flow and the maximum amount of mechanical energy available.

If L is a work, Q is heat, T is a temperature in °K, Carnot states that:

$L = Q(1 - Tc/Th)$ and the ratio L/Q is called yeald. So, due to II Law, the available work L depend as of amount of thermal energy as of the difference between hot source and cold source. This put a limit in conversion of energies: not all thermal energy can become mechanical work: a difference of temperature must be present.

1.2.1.3. Third Law of Thermodynamics

The third law of thermodynamics states that if all the thermal motion of molecules (kinetic energy) could be removed, a state called absolute zero would occur. Absolute zero results in a

Temperature of 0 Kelvins or -273.15° Celsius.

Absolute Zero = 0 Kelvins = -273.15° Celsius

The Universe will attain absolute zero when all energy and matter is randomly distributed across space. The current temperature of empty space in the Universe is about 2.7 Kelvins.

1.2.2. Forms of Energy

Some of the many forms that energy takes are:

- Mechanical energy, which includes
  - Potential energy, stored in a system.
  - Kinetic energy, from the movement of matter.
- Radiant or solar energy, which comes from the light and warmth of the sun.
- Thermal energy, associated with the heat of an object.
- Chemical energy, stored in the chemical bonds of molecules.
- Electrical energy, associated with the movement of electrons.
- Electromagnetic energy, associated with light waves (including radio waves, microwaves, x-rays, infrared waves).
- Mass (or nuclear) energy, found in the nuclear structure of atoms.

Mechanical energy

Potential energy: Potential energy appears in many different forms, and is defined as the energy in matter due to its position or the arrangement of its parts. The various forms of potential energy include gravitational potential energy, elastic potential energy, chemical potential energy, and electrical potential energy. Potential Energy is often referred to as stored energy. Some scientists avoid use of the word "stored" because it inaccurately depicts energy as a substance that is contained within a substance. In other words, some scientists and energy educators believe saying energy is "stored" is a misconception. Various forms of potential energy can be classified like below:

- *Gravitational Potential Energy:* When something is lifted or suspended in air, work is done on the object against the pull of gravity. This work is converted to a form of potential energy called gravitational potential energy. When the item succumbs to the force of gravity, falling towards Earth like an apple from a tree, it converts potential energy into kinetic energy. A potential energy become from a potential field. The important feature of potential fields is that difference of energy is a function of space points. So if Pa is starting point and Pb is ending point of a mass M, a variation of potential energy depend only from Pa – Pb and not from paths to go between. The gravitational force is the gradient of gavitational field, so on earth the potential energy is a simple equation between g (acceleration), h(heigth from ground), m (mass of body) : $E_p = m*g*h$

- *Elastic Potential Energy:* A stretched rubber band has the potential to do work or change things. This form of energy is called elastic potential energy. It occurs when an object (such as our skin, a spring, a trampoline, or a rubber band) resists being stretched out of shape. The elastic potential energy in a rubber band can be used to do work. For example, toy airplanes fly when a rubber band untwists and spins a propeller. The elastic potential energy in the rubber band was converted into kinetic energy. This potential is due to attractive forces between atoms in a solid body. All bodies in a force's filed, show a deformation that has a proportional from force applied to. If deformation is small the process is reversible, so bodies can accumulate mechanical energy in potential elastic field and next provide mechanical energy from elastic potential. Again the equation between elastic constant, deformation and energy is (we consider only the monodimensional field) $E_p = kx^2/2$.
- *Chemical Potential Energy:* It would take millions of rubber bands to move a real airplane, so gasoline is used instead. But you don't stretch gasoline to make it work, you burn it. The chemical makeup (arrangement of molecules) of gasoline makes it a good fuel source. All nonliving and living things, from

automobiles to zebras, are made up of molecules. It takes energy to make these molecules and hold them together. The energy stored in molecules is called chemical potential energy. During combustion, bonds are broken and reformed creating new products. The energy stored in gasoline is released by burning it (combustion). During combustion, chemical bonds are broken and reformed (changing gasoline into byproducts such as water and carbon dioxide) releasing energy. The airplane motor uses this released energy to turn a propeller. There are many examples of chemical potential energy being converted to kinetic energy to do work. The chemical energy in food is used by our bodies to move. In a lighted firecracker chemical energy is used to make a loud sound and to scatter pieces of the firecracker all over.

- *Electrical (Electromagnetic) Potential Energy*: A battery has chemical potential energy along with electrical potential energy. When you turn on a device that is battery-operated, such as a flashlight or a toy, the electrical potential energy stored in the battery is converted into other forms of energy such as sound, mechanical motion, thermal energy, and light. For an electrical appliance you plug in, the electrical potential energy is maintained by a spinning generator of a power plant, hydroelectric dam, or a windmill. A solar cell stores electrical potential energy similar to a battery as long as the sun is shining on it.
- *Thermal Energy:* When you feel a warm object, you are actually feeling thermal energy, which is the movement of molecules that make up the object. All objects possess thermal energy (even cold ones) since they have a temperature above absolute zero. Evidence of thermal energy can be detected by measuring the temperature of an object.

Kinetic energy: Kinetic energy is energy of motion. The kinetic energy of an object is the energy it possesses because of its motion - whether it be vertical or horizontal motion -. Kinetic energy is an expression of the fact that a moving object can do work on anything it hits; it quantifies the amount of work the object could do as a result of its motion. There are many forms of kinetic energy - vibrational (the energy due to vibrational motion), rotational (the energy due to rotational motion), and translational (the energy due to motion from one location to another). The total mechanical energy of an object is the sum of its kinetic energy and potential energy.

For an object of finite size, this kinetic energy is called the translational kinetic energy of the mass to distinguish it from any rotational kinetic energy it might possess - the total kinetic energy of a mass can be expressed as the sum of the translational kinetic energy of its center of mass plus the kinetic energy of rotation about its center of mass.

Radiant or solar energy: Radiant or solar energy is the energy of electromagnetic waves. The quantity of radiant energy may be calculated by integrating radiant flux (or power) with respect to time and, like all forms of energy. The term is used particularly when radiation is emitted by a source into the surrounding environment. Radiant energy may be visible or invisible to the human eye.

The term "radiant energy" is most commonly used in the fields of radiometry, solar energy, heating and lighting, but is also sometimes used in other fields (such as telecommunications). In modern applications involving transmission of power from one location to another, "radiant energy" is sometimes used to refer to the electromagnetic waves themselves, rather than their energy (a property of the waves). In the past, the term "electro-radiant energy" has also been used.

Radiant or solar energy of the sun reaches earth in the form of electromagnetic wave energy. This energy is used for many purposes, such as being transformed into chemical energy by plants, transformed into heat and mechanical energy in humans, transformed into electrical energy by solar panels, etc.

When solar energy is changed or transformed it becomes either potential or kinetic energy. When a plant converts solar energy into chemical energy it is now potential energy because the plant is storing the energy. When a human changes solar energy into heat energy to warm the body, it is potential energy. When a human changes solar energy into mechanical energy called work (kinetic energy): he/she moves muscles for walking or lifting objects.

Electrical energy: Electricity is the flow of electrical power or charge. Electrical energy is the scientific form of electricity, and refers to the flow of power or the flow of charges along a conductor to create energy. It is both a basic part of nature and one of our most widely used forms of energy. Electricity is actually a secondary energy source, also referred to as an energy carrier. That means that we get electricity from the conversion of other sources of energy, such as coal, nuclear, or solar energy. These are called primary sources. Electrical energy is known to be a secondary source of energy, which means that we obtain electrical energy through the conversion of other forms of energy. These other forms of energy are known as the primary sources of energy and can be used from coal, nuclear energy, natural gas, or oil. The primary sources from which we create electrical energy can be either non-renewable forms of energy or renewable forms of energy. The energy sources we use to make electricity can be renewable or non-renewable, but electricity itself is neither renewable or nonrenewable. Electrical energy is a standard part of nature, and today it is our most widely used form of energy. Many towns and cities were developed beside waterfalls which are known to be primary sources of mechanical energy. Wheels would be built in the waterfalls and the falls would turn the wheels in order to create energy that fueled the cities and towns. Before this type of electrical energy generation was developed, homes would be lit with candles and kerosene lamps, and would be warmed with coal or wood-burning stoves.

Electromagnetic energy: There is a great deal of confusion about who exactly discovered electromagnetic waves, electromagnetic radiation or electromagnetic energy. In short, the definition of electromagnetic energy can be given as, the energy source required to transmit information (in the form of waves) from one place (material) to another. This information can be in the form of light, heat, or in any other form.

Mass (or nuclear) energy: Nuclear energy; the energy stored in the nucleus of an atom and released through fission, fusion, or radioactivity Nuclear energy is released by the splitting (fission) or merging together (fusion) of the nuclei of atom(s). Nuclear energy comes from mass-to-energy conversions that occur in the splitting of atoms larger than Iron or joining atoms smaller than Iron. The small amount of mass that is lost in either of these events follows Einstein's famous formula. The conversion of nuclear mass to energy is consistent with the mass-energy equivalence formula $\Delta E = \Delta m.c^2$, in which ΔE = energy release, Δm = mass defect, and c = the speed of light in a vacuum (a physical constant).

Nuclear energy originates from the splitting of uranium atoms in a process called fission. At the power plant, the fission process is used to generate heat for producing steam, which is used by a turbine to generate electricity.

1.3. Use of Energy

Technical conversion of energy has different conversion stages: primary energy, final energy and effective energy. These stages are explained in Table 1.1.

Table 1.1. Energy conversion stages [1]

Term	Definition	Examples
Primary energy (energy sources)	Original energy, not yet processed	e.g. crude oil, coal, uranium, solar energy, wind energy.
Final energy (secondary energy)	Energy in the form that reaches the end user	e.g. gas, fuel oil, electricity, hot water, steam
Effective energy (end-use energy)	Energy in the form used by the end user	e.g. light, radiator heat, driving force of machines or vehicles

1.3.1. Energy Sources

Energy is a fundamental component to our daily lives, and everyday we use energy or power in some form or another. The law of conservation of energy states that energy can neither be created or destroyed. What this means is that as energy is used, it does not disappear, but rather, is converted into another form of energy. For example, automobiles use energy from gas that is converted into chemical energy which is further converted into mechanical energy. Thus, energy is all about performing work. Animals and humans require **energy sources** in order to function, and machines do not function any differently, they require energy sources to work as well. Figure 1.1. shows the energy conversion chain schematically.

There are many different energy sources on our planet, but they are all classified into two primary groups – renewable energy sources, and non renewable energy sources.

Renewable energy sources are energy sources that are directly available, immediately accessed, and can be consistently replaced. In other words, renewable energy sources are energy sources that replace, or renew themselves and that will never run out. Solar energy, energy that is harnessed form the sun, is a good example of one of many renewable energy sources, because we will never run out of the sun’s rays or its power. Other examples of renewable energy sources include wind energy, water energy, and wave energy.

Non renewable energy sources on the other hand are just the opposite. These energy sources are as the name implies, non renewable. Our Earth is fixed with a finite amount of these energy sources, and once we run out, we will not be able to use those energy sources ever again. Fossil fuels, coal, oil, and gas, are all examples of non renewable energy sources.

There are many different **energy sources** available to us on this planet. Unfortunately, whether our energy sources are renewable or non renewable is not the only issue that we are facing in today's world of global climate changes. When we use energy resources, we also need to keep in mind that energy generation and production also has the potential to impact our environment in a negative manner. Energy production is known to produce pollutants and toxins to our environment, and this very issue is a direct cause of our global climate change.

It is well documented that using renewable energy sources is the most environmentally friendly means of not only using readily available and free resources, but of protecting our environment as well. For example, using the sun as an energy resource is much more environmentally friendly that burning coal and releasing toxins into the atmosphere. Today's world is one where not only cost and availability are concerns with energy resources, but also the effects on our environment [2].

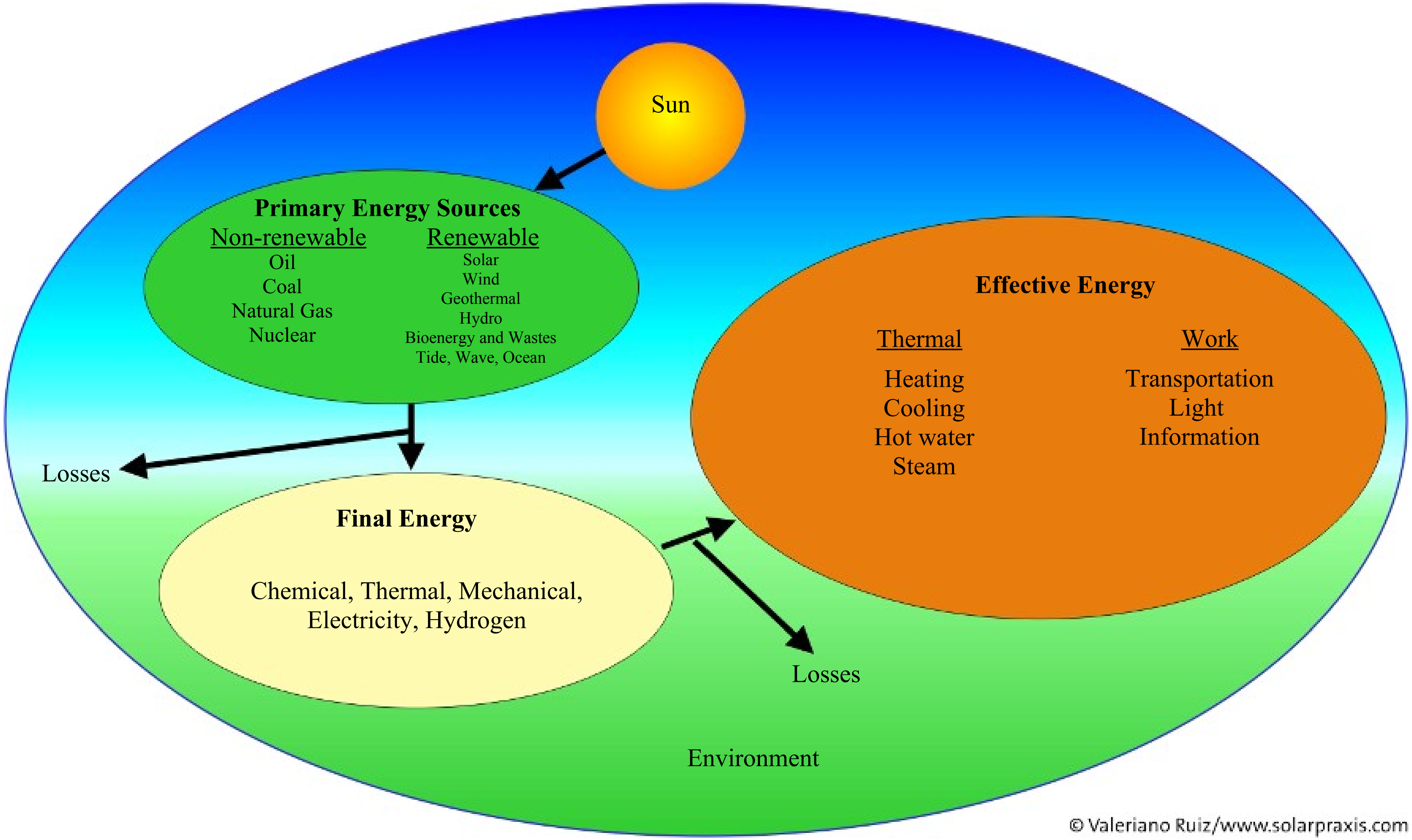

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Figure 1.1. Conversions of energy [3]

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[1] Volker Quaschning, Understanding Renewable Energy Systems, Earthscan, ISBN: 1-84407-128-6, 2005.

[2] WEB_1, http://www.ifpaenergyconference.com/Energy-Resources.html, 2009.

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CHAPTER 2

RENEWABLE ENERGY SOURCES

2.1. Renewable Energy Sources

2.1.1. Solar Energy

Solar radiation exploited for hot water production and electricity generation.

- ***Solar thermal technologies*** provide heat and hot water for residential, commercial and industrial end uses, and have a long history of commercial use. For many of the applications the technologies are now reasonably mature, and recently developed cost reductions have brought them into the competitive range.
- ***Solar thermal electric technologies***, also known as concentrating solar power (CSP), create heat to produce steam and/or electricity. Commercial applications, from a few kilowatts to hundreds of megawatts, are now technically feasible though not yet economically competitive. Plants can function in dispatchable, grid-connected markets or in distributed, stand-alone applications. CSP can meet dispatchability requirements through thermal storage or in a hybrid configuration with fossil generation.
- ***Photovoltaics (PV)***, the use of semiconductor materials to convert sunlight directly into electricity, have dropped in price to between one-third and one-fifth their cost in 1980. PV is now widely viewed as cost competitive for many grid-connected, building-integrated uses, and for off-grid applications ranging from telecommunications to village power.

2.1.2. Wind Energy

Kinetic energy of wind exploited for electricity generation in wind turbines. Wind energy is seen as one of the most promising technologies for electricity generation and the costs, in good wind regimes, are comparable to fossil alternatives, particularly when economic or environmental circumstances are considered.

2.1.3. Geothermal Energy

Energy available as heat emitted from within the earth’s crust, usually in the form of hot water or steam. It is exploited at suitable sites for electricity generation after transformation, or directly as heat for district heating, agriculture, etc. Geothermal technology is mostly used for power generation, though its use for space heating is becoming increasingly important.

Geothermal electricity generation is a baseload technology, and can be a low-cost option if the hot water or steam resource is at a high temperature and near the earth's surface.

2.1.4. Hydropower

Potential and kinetic energy of water converted into electricity in hydroelectric plants. It includes large as well as small hydro, regardless of the size of the plants. Hydropower is the most mature form of renewable energy and has a significant share of electricity generation worldwide. While expansion of large-scale hydro has been hampered due to environmental constraints, there is considerable interest and potential in small hydro applications.

2.1.5. Bioenergies and Wastes

Solid Biomass: Covers organic, non-fossil material of biological origin which may be used as fuel for heat production or electricity generation. Wood, Wood Waste, Other Solid Waste: Covers purpose-grown energy crops (poplar, willow etc.), a multitude of woody materials generated by an industrial process (wood/paper industry in particular) or provided directly by forestry and agriculture (firewood, wood chips, bark, sawdust, shavings, chips, black liquor etc.) as well as wastes such as straw, rice husks, nut shells, poultry litter, crushed grape dregs etc.

Charcoal: Covers the solid residue of the destructive distillation and pyrolysis of wood and other vegetal material.

Biogas: Gases composed principally of methane and carbon dioxide produced by anaerobic digestion of biomass and combusted to produce heat and/or power.

Liquid Biofuels: Bio-based liquid fuel from biomass transformation, mainly used in transportation applications.

Municipal Waste (renewables): Municipal waste energy comprises wastes produced by the residential, commercial and public services sectors and incinerated in specific installations to produce heat and/or power. The renewable energy portion is defined by the energy value of combusted biodegradable material.

Biomass resources are available worldwide, coming in a variety of forms: wood, grasses, crops and crop residues. These can be converted to energy through thermal or biological conversion or as feedstock to produce different kinds of liquid or gaseous biofuels. A large number of projects are underway to determine how to use biomass even more cost-effectively for energy production. Biomass-based electricity has the important advantage of being a base load technology and can be CO_2 neutral.

2.1.6. Tidal/Wave/Ocean Energy

Mechanical energy derived from tidal movement, wave motion or ocean current, and exploited for electricity generation. Oceans contain various energy sources: tidal forces, ocean currents, wave power and thermal gradients can all be captured to produce electricity, using technology similar to underwater windmills, and these are starting to be deployed. Ocean energy systems need a relatively extended R&D effort, but full-scale prototypes have been constructed.

2.2. Current Status of Renewable Energy in the World

Renewable energies are essential contributors to the energy supply portfolio as they contribute to world energy supply security, reducing dependency on fossil fuel resources, and provide opportunities for mitigating greenhouse gases. Renewable energy is proving to be commercially viable for a growing list of consumers and uses. Renewable energy technologies provide many benefits that go well beyond energy alone. More and more, renewable energies are contributing to the three pillars of sustainable development – the economy, the environment and social well-being all over the world.

The development and deployment of renewable energy technologies are important components for the future of a balanced global energy economy. Renewables can make major contributions to the diversity and security of energy supply, to economic development, and to addressing local environmental pollution. In addition, considerable attention has been attracted to their potential to address global warming through zero or near zero net greenhouse gas emissions. Due to the fossil fuel usage carbon emission during the last century increased to very high level (see Figure 2.1.)

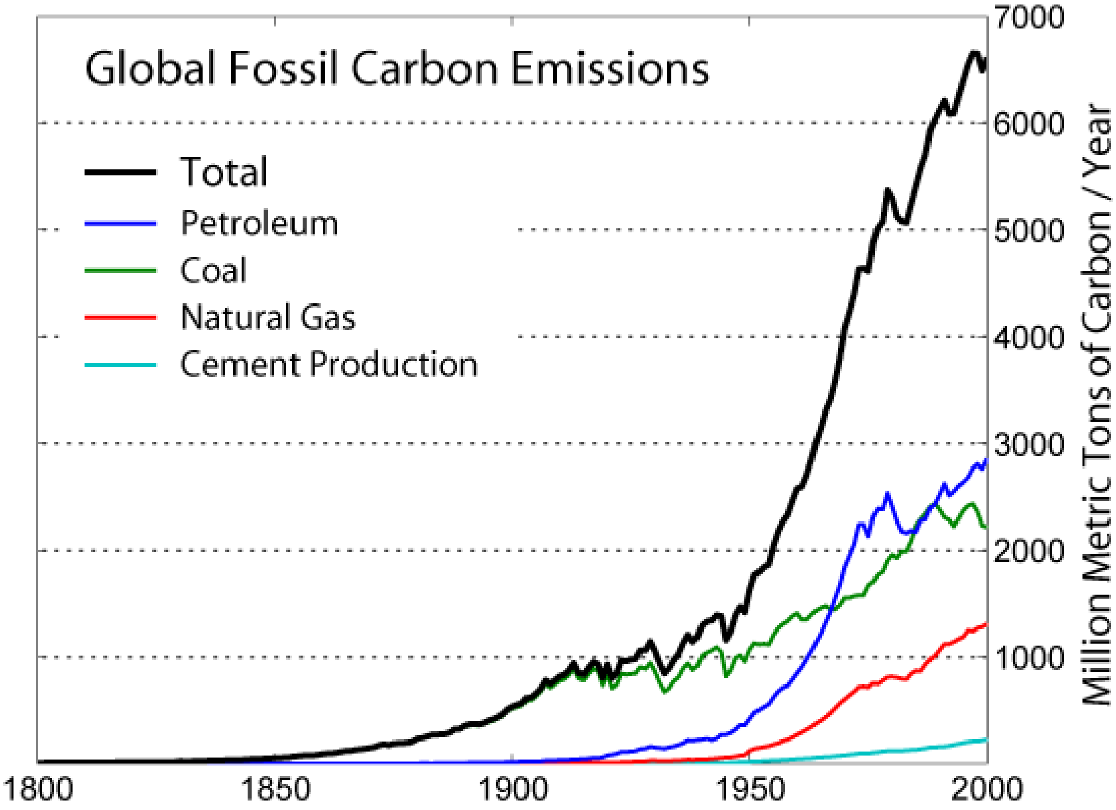


Figure 2.1. Global Fossil Carbon Emmision during the last century.

Renewable energy supplies 18 percent of the world's final energy consumption, counting traditional biomass, large hydropower, and "new" renewables (small hydro, modern biomass, wind, solar, geothermal and biofuels). (See Figure 2.2.) Traditional biomass, primarily for cooking and heating, represents about 13 percent and is growing slowly or even declining in some regions as biomass is used more efficiently or replaced by more modern energy forms. Large hydropower represents 3 percent and is growing modestly, primarily in developing countries. New renewable represent 2.4 percent and are growing very rapidly in developed countries and in some developing countries. Clearly, each of these three forms of renewable energy is unique in its characteristics and trends. This report focuses primarily on new renewables because of their large future potential and the critical need for market and policy support in accelerating their commercial use.

Renewables are the second largest contributor to global electricity production. Most of the electricity generated from renewables comes from hydro plants (92%) followed by combustible renewables and waste (5%) and "new" renewable (3%) including geothermal, solar, wind, tide and others. Renewable energy can play a fundamental role in tackling climate change, environmental degradation and energy security. As these challenges have become ever more pressing, governments and markets are seeking innovative solutions.

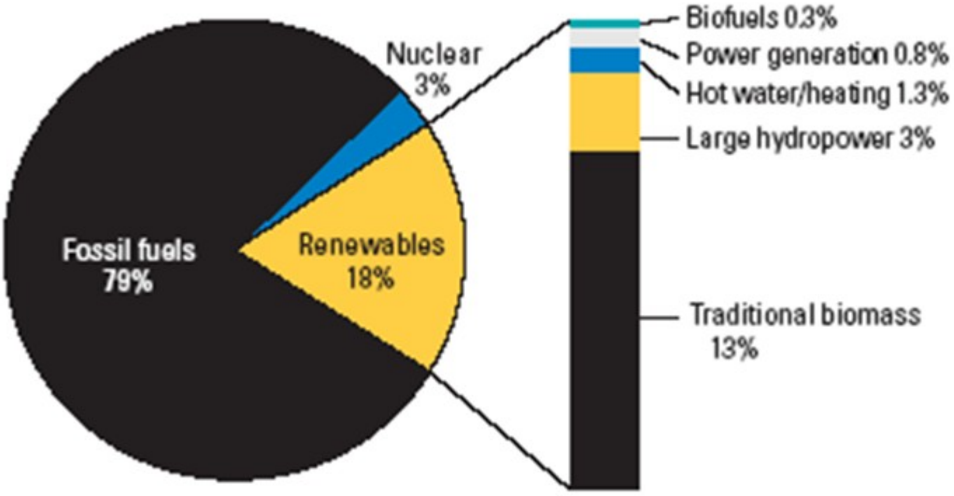


Figure 2.2. Fuel Shares of World Total Primary Energy Supply

Renewable energy replaces conventional fuels in four distinct sectors: power generation, hot water and space heating, transport fuels, and rural (off-grid) energy. In power generation, renewable energy supplies about 18 percent of global electricity production (excluding large hydropower). Renewables are the third largest contributor to global electricity production. They accounted for almost 18% of production in 2004, after coal (40%) and natural gas (close to 20%), but ahead of nuclear (16%), and oil (7%) and nonrenewable waste. Almost 90% of electricity generated from renewables comes from hydropower plants while close to 6% comes from combustible renewables and waste. Geothermal, solar and wind have now reached 4.5% of renewable generation (See Figure 2.3. and 2.4).

Hot water and space heating for tens of millions of buildings is supplied by biomass, solar, and geothermal. Solar hot water collectors alone are now used by an estimated 50 million households worldwide, most of these in China. Biomass and geothermal also supply heat for industry, homes, and agriculture. Biofuels for transport make small but growing contributions in some countries and a very large contribution in Brazil, where ethanol from sugar cane displaces over 40 percent of the country’s gasoline consumption. In developing their homes with solar photovoltaics (PV); and a growing number of small industries, including agricultural processing, obtain process heat and motive power from small-scale biogas digesters.

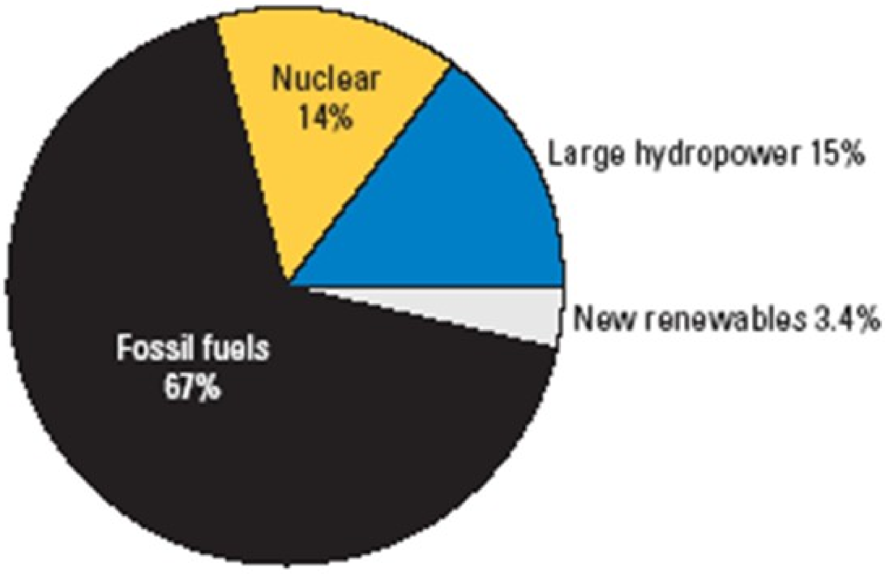
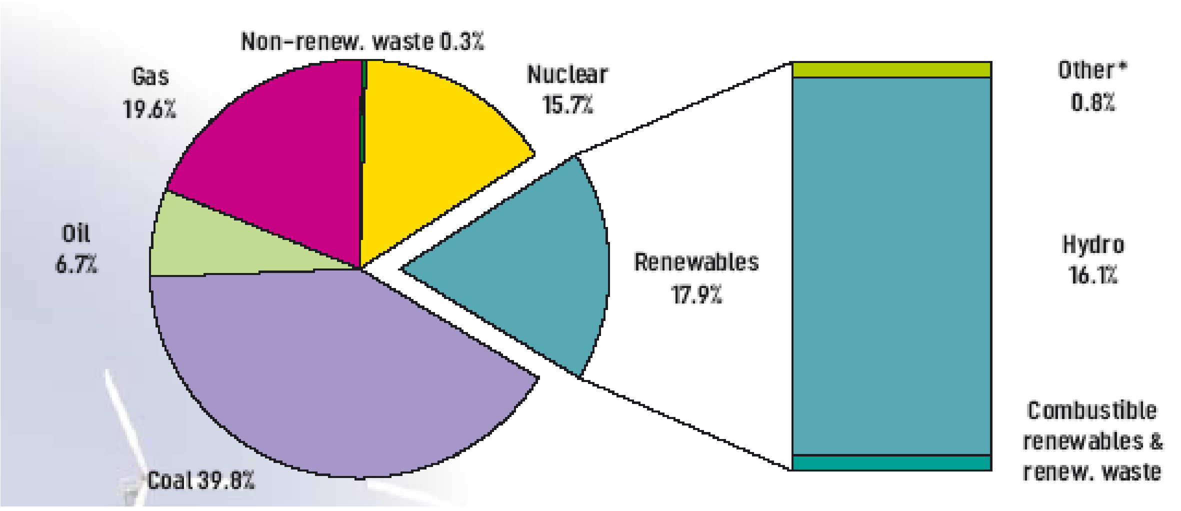


Figure 2.3. Share of energy source for electricity generation



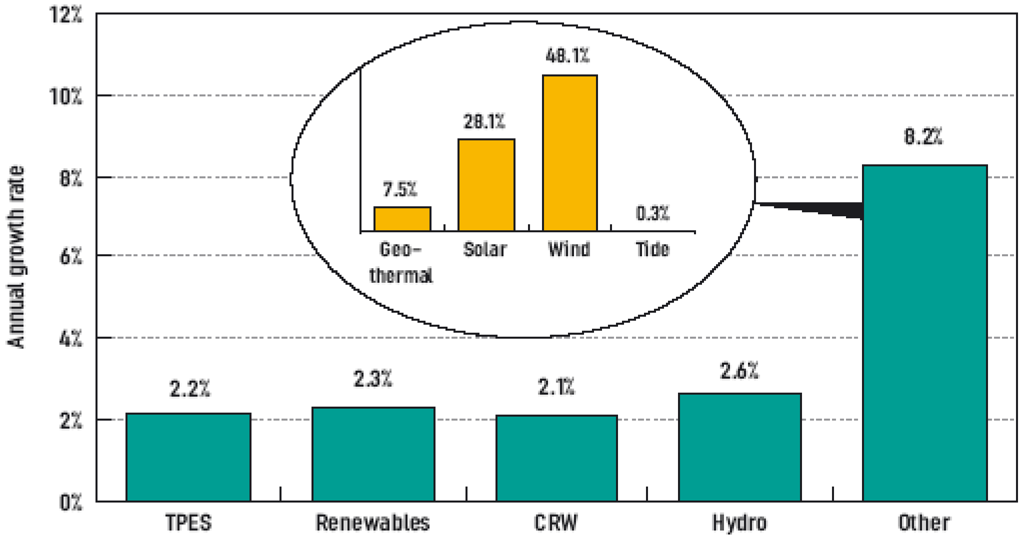
* Geothermal, solar, wind, tide/wave/ocean.

Source: IEA Energy Statistics

Figure 2.4. 2004 Renewables in Electricity Production

Several renewable energy technologies are established in world markets, and are building global industries and infrastructures. Other renewables are fast becoming competitive in growing markets, and some are widely recognized as the lowest cost option for stand-alone and offgrid applications. The capital costs for many renewable energy technologies have been halved over the last decade and these are expected to halve again over the next decade.

Despite the small contribution to global electricity production, “new” renewables made remarkable progress during the past decades growing by an average of 9.3% per annum during the period 1971-2004. These growth rates reflect a 48.1% p.a. growth in wind energy, 28.1% p.a. growth in solar energy and 7.5% p.a. growth in geothermal energy during this period (Figure 2.5).

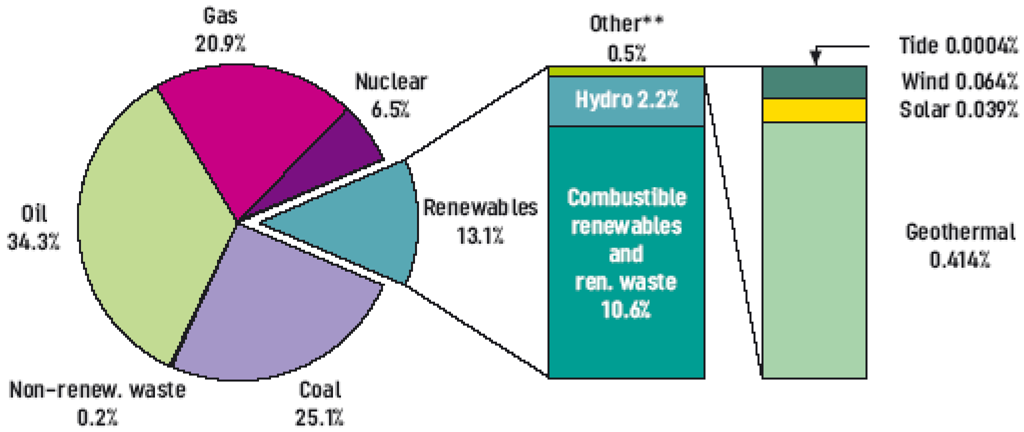


Source: IEA Energy Statistics

Figure 2.5. Annual Growth of Renewables Supply from 1971 to 2004

Global renewable energy capacity grew at rates of 15–30 percent annually for many technologies during the five-year period 2002–2006, including wind power, solar hot water, geothermal heating, and off-grid solar PV. The growth of grid-connected solar PV eclipsed all of these, with a 60 percent annual average growth rate for the period. Biofuels also grew rapidly during the period, at a 40 percent annual average for biodiesel and 15 percent for ethanol. Other technologies are growing at more ordinary rates of 3–5 percent, including large hydropower, biomass power and heat, and geothermal power; although in some countries these technologies are growing much more rapidly than the global average. These growth rates compare with global growth rates for fossil fuels of 2–4 percent in recent years (higher in some developing countries).

Figure 2.6. represents the main fuels in the world total primary energy supply (TPES), with a disaggregation of the share of the main renewables categories. In 2004, renewables accounted for 13.1% of the 11 059 Mtoe of world total primary energy supply. Combustible renewables and waste (97% of which is biomass, both commercial and non-commercial) represented 79.4% of total renewables followed by hydro (16.7%).



Source: IEA Energy Statistics

Figure 2.6. Main fuels in the world total primary energy supply

The global share of renewables in electricity generation will increase from 18% today to 19% by 2030. The development of renewable-based power is expected to cost about USD 1.6 trillion, nearly 40% of power generation investment over the period.

The second generation of renewables have been commercially deployed, usually with incentives in place intended to ensure further cost reductions through increased scale and market learning. Markets for these technologies are strong and growing, but only in a few countries. Some of the technologies are already fully competitive in favourable circumstances but for others, and for more general deployment, further cost reductions are needed. The challenge is to continue to reduce costs and broaden the market base to ensure continued rapid market growth worldwide. These technologies have very broadly followed the rule that each doubling of deployed capacity leads to a 20% reduction in investment cost. On this basis the potential for further cost reductions is considerable.

Third-generation renewables are not yet widely demonstrated or commercialised. They are on the horizon and may have estimated high potential comparable to other renewable energy technologies. However, they still depend on attracting sufficient attention and RD&D funding.

2.3. The Benefits of Renewables

The potential contribution of renewables is growing, as the technologies mature and there is increasing awareness of the full contribution that renewables can make. The benefits from renewables amount to more than just their contribution to energy balance alone, because costs of energy output (e.g. per kWh) do not adequately capture a number of important values to society. Renewables add to the diversity of the energy supply portfolio and reduce the risks of continued (or expanded) use of fossil fuels and nuclear power.

Distributed renewables provide options to consumers not otherwise available because of their deployment close to use. Renewable energy is also the most environmentally benign energy supply option available in current and near-term markets. Finally, renewable contribute to a healthy economy, both in their contribution to the efficiency of the energy system, and in the employment and investment opportunities that arise from continued rapid market growth.

The recent slowdown in growth rates of hydropower, biomass and geothermal has driven changes in the share of renewables in the TPES of IEA countries. The renewables share increased from 4.6% in 1970 to 5.8% in 1990, then declined to 5.5% in 2001.

In urban areas, renewables contribute to energy supply diversity and to local economic development. In rural areas, renewables can be the key to aspirations for development, and can contribute to agricultural productivity, health, education, communications, entrepreneurship, and home quality. They can contribute to local economic development, expanded industrial capacities and even export capabilities.

In this regard, they can support aspirations for progress and equality. Over 1.6 billion people, in parts of the developing world where population is growing most rapidly, are still without modern energy services such as lighting, fresh water and many other services. While considerable efforts have been made through various bilateral and multilateral aid programmes to provide better services over the past two decades, there has been a large core of people who have not reaped the benefits of modern electric services. The new generation of renewable energy technologies provides a relatively low-cost, cost-effective means to provide such services.

Many renewables are well suited for off-grid uses. Their operational costs are often lower and, once operational, are not subject to the fluctuations of energy prices. Reducing the need to extend grids also reduces costs significantly. The expanded use of renewables can not only help support local manufacturing and thus create local employment, but their increased use can also provide environmental benefits. For example, by improving the efficiency of wood stoves, a new generation of renewable energy technologies can reduce the negative health effects of indoor pollution, as well as reducing the impacts of collecting wood for fuel from a widening area around a village.

The main advantages of renewable energy sources can be as follows:

- They are practically inexhaustible sources of energy and contribute to reducing dependence on conventional energy resources.
- They are an answer to the energy problem for the stabilization of carbon dioxide emissions and other greenhouse gases. In addition, by replacing energy generation plants which use conventional resources, they lead to a reduction in the emission of other pollutants, such as sulfur and nitrogen oxides which cause acid rain.
- They are domestic sources of energy and contribute to increasing energy independence and security of energy supply at the national level.
- They are geographically dispersed, leading to the decentralization of the energy system, making it possible for energy needs to be met at a local and regional level, thus relieving infrastructure systems and reducing losses from energy transmission.
- They provide opportunities for the rational use of energy sources because they cover a wide range of users' energy needs (i.e. solar energy for low temperature heat, wind energy for electricity production).
- They usually have low operating costs which are not influenced by fluctuations in the international economy and especially in prices for conventional fuels.
- RES investments create a significant number of new jobs, especially at the local level.
- In many cases, they can be a catalyst for the renewal of economically and socially depressed areas and a magnet for local development through the promotion of relevant investments) for example, greenhouses using geothermal energy).

2.3.1. Energy security

Recent oil price volatility highlights the need to be continuously concerned about energy security. Dependency on oil imports for the countries expected to grow significantly in coming decades. Such dependency over an extended period is unsustainable. Renewable energy can relieve some of that increasing need for imported fossil fuels, and reduce dependence on foreign sources. The distributed capability of renewables-based generating capacity brings generation closer to the end-use, thus minimising transmission concerns and costs. The Renewable Energy Working Party also believes that greater use of renewables in the energy portfolio can minimise overall generation costs relative to the risk. Energy policies should focus on developing efficient generating portfolios that do not solely rely on stand-alone costs but also on expected portfolio risk, including year-to-year cost fluctuations.

2.3.2. Environment

Directly or indirectly, environmental concerns dominate the thrust for expanded deployment of renewable energy technologies. Climate change concerns that arose during the late 1980s have created a new impetus for clean, low-carbon energy technologies, such as renewable energy technologies. The main reason for the CO2 emission increases is fossil fuel combustion (see Figure 2.7.).

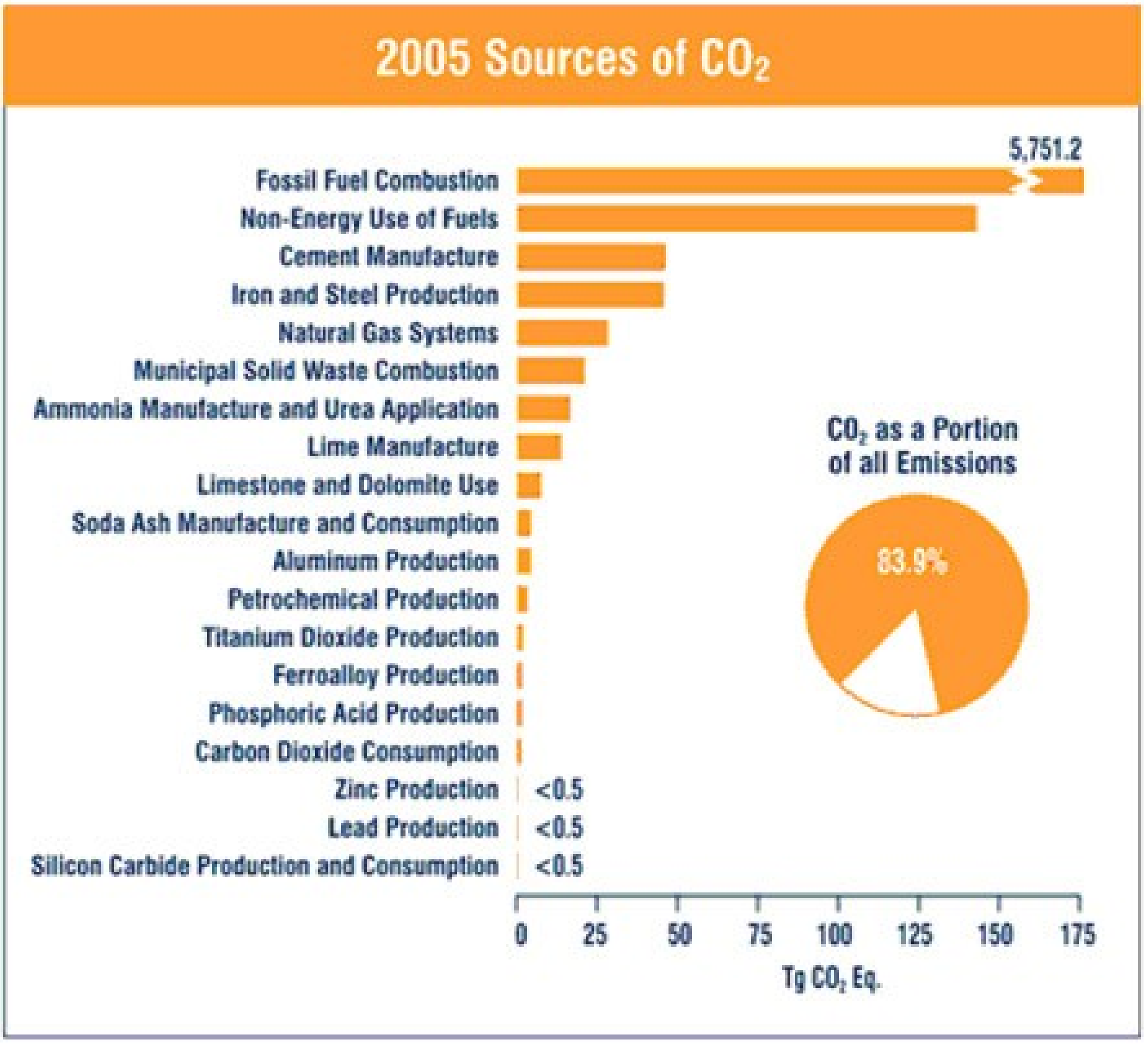


Figure 2.7. The sources of CO_2 emmision

Renewable energy received important backing from the Kyoto UN Climate Change Conference in December 1997. The greenhouse gas emissions reduction targets of the Kyoto Protocol imply that developed countries will pay particular attention to renewable energy because of its great potential for reducing global greenhouse gas emissions.

However, while renewables can contribute to resolving environmental issues, including global climate change, there are still some environmental issues to be addressed. Particularly at the local level, concerns such as land use, interruption of animal and bird migration patterns, noise and visual impacts, all need to be addressed in siting renewable facilities. The Renewable Energy Working Party believes that, on balance, renewables offer the best-cost strategy in achieving environmental goals.

2.3.3. Economic growth

Renewable energy has several important economic benefits. The main economic benefits are employment creation and increased trade of technologies and services.

2.3.4. Employment

There are important job creation benefits from a strategy for greater promotion of renewable energy technologies. Employment is created at different levels, from research and manufacturing to services, such as installers and distributors. Renewable energy has created more than 14 million jobs worldwide 3; every renewable energy industry is rapidly expanding its workforce.

2.3.5. Trading technologies and services

Renewable energy technologies and related services have a domestic market appeal but they can also drive exports to meet the growing international demand. For example, Denmark's successful wind turbine industry is a model of how to become a world leader in exporting technology and services. Denmark maintains a hold on more than 40 per cent of the world Market and its companies' sales increased 10 times in nominal terms between 1988 and 1997.

The Renewable Energy Working Party believes that renewables generate a wealth of economic benefits that increase their value to society beyond the power they provide.

2.4. Priorities for Key Technologies

Experience over the last 30 years shows that the move towards sustainable renewable energy options depends on resource availability, technical maturity and a policy environment that is conducive to both technology improvements and commercialisation. Because of the diverse nature of renewables, each country or region must promote technologies and options best suited to its own resources and needs.

Bioenergy in all its forms represents the largest current source of renewable energy and could play a major role in a low carbon energy economy of the future. It includes traditional low technology practices in rural economies, some of which will run down as modern energy becomes available, as well as advanced technologies, such as ethanol vehicle fuels, which already play a major role. In the short term, the key challenge is to make available relatively cheap feedstocks and to develop standards and norms for trading. In the medium term, there is a range of advanced conversion technologies with great potential, including bio-refineries capable of simultaneously producing a range of products, including energy, as well as further development of facilities producing ethanol from lignocellulosics. Key technologies for the longer term include those for the production of hydrogen from biomass and the development of sustainable ways to produce large amounts of feedstock worldwide. More effort is needed on the social and environmental acceptability of large-scale bioenergy across the complete chain, i.e., from biofuel production to the delivery of services to the consumer.

Achieving greater energy supply from hydropower does not require technological breakthroughs, huge RD&D expenditures, or radical changes to the development of hydropower resources. Current requirements include continuous improvements in technology, increased public acceptance, and more efficient hydropower project approval processes supported by government policy. The technology is at a stage where implementation and development should be financed and supported jointly by the public and private sectors. Geothermal power is, in some respects, a mature technology with a long history in many countries. However, there are several priority RD&D areas that offer the potential to accelerate its advancement worldwide. These would provide cost reduction, sustainable use, and the expansion of the technology for new applications. The benefits would include an extension of the use of geothermal, both for power generation and direct heat use, to cover much larger regions that are farther away from tectonic plate boundaries. More funding and manpower is needed for more rapid achievement of these priorities.

During the last five years, industry RD&D placed emphasis on developing larger and more effective wind energy systems, using knowledge developed from national and international generic RD&D programmes. Between 1981-98, production costs of wind turbines have been reduced by a factor of four, making wind energy cost competitive with other forms of electricity generation in favourable locations. Continued RD&D is essential to explore revolutionary new designs as well as for incremental improvements to provide the reductions in cost and uncertainty needed for widespread deployment. Research is needed to improve our understanding of aerodynamics and extreme wind situations, on aspects of grid integration, forecasting techniques, minimising environmental impacts, and on public attitudes to deployment.

In addition to space exploration and consumer products, Photovoltaics (PV) are now in fully commercial use for illuminating signs, for water pumping, for lighting at remote locations, and for many other purposes. For mainstream power use, however, PV costs must come down substantially. While costs of PV are currently very high compared to other forms of generation, PV has great potential for future cost reductions. It is estimated that about half of the future cost reductions for PV will be the result of RD&D to improve materials, processes, conversion efficiency and design. Substantial cost reductions can also be gained through increasing manufacturing volume and streamlining installation procedures.

A comprehensive and ambitious applied RD&D programme is needed to develop competitive, advanced Solar Heating and Cooling (SHC) systems. RD&D efforts need to focus on technical advances in material and components, storage, scaling up and increasing efficiency. They also need to include architecture, so that solar thermal collectors can gain the status of standard building components.

Solar radiation is the largest renewable source on Earth and Concentrating Solar Power (CSP) is a serious candidate to provide a major share of the clean renewable energy that will be needed in the future. It can be sized for remote village applications as well as for gridconnected applications. However substantial cost reductions are needed before it can compete directly with conventional grid sources. There is considerable potential for cost reductions through increased scale; for this reason, incentive schemes should avoid restrictions on size. Better technology, including improvements in concentrator performance and cost, could also bring down the cost of CSP electricity dramatically. Improved storage systems could also contribute to cost reductions. New deployment efforts are also needed for CSP, which is not well served by many existing national renewable electricity incentive schemes. There may be potential for exporting CSP, for instance from well-endowed regions such as North Africa into Europe.

The oceans contain a huge amount of power capable of being exploited to generate useful energy. However, technologies to extract ocean energy are at an early stage compared to other sources of renewable energy, with a wide range of prototypes under consideration. Ocean energy technologies must solve two major problems concurrently: proving the energy conversion potential and overcoming a very high technical risk from the harsh environment of strong waves or currents. They also need to fulfil basic economic and environmental requirements including low cost, safety, reliability, simplicity, and low environmental impact.

Every ocean energy concept has its own technical challenges that require RD&D work. However Research and Development (R&D) on resource potential, energy production forecasting, simulation tools, test and measurement standards, and environmental impact, can address common barriers. Additional RD&D funding is needed to mitigate the substantial technical risk faced by device developers daring to harness the vast energies of the marine environment.

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CHAPTER 3

RENEWABLE ENERGY TECHNOLOGIES

3.1. Introduction

The combined technical and economic status of a technology can be classified into one of the following four stages [1]:

1. 'Economic' technologies which are well developed and economically viable at least in some markets and locations; further market penetration will require technology refinements, mass production, and/or economies of scale;
2. 'Commercial-with-incentives': technologies which are available in some markets but are competitive with the conventional technologies only with preferential treatments such as subsidies; these technologies still need further technology refinements, mass production, and economies of scale;
3. 'Under-development': technologies which need more research and development to improve efficiency, reliability or cost so as to become commercial; this would include materials and systems development, pilot plants or field experiments to resolve operational problems and environmenl impacts and demonstration plants to illustrate performance capabilities and to establish cost and performance capabilities of specific applications;
4. 'Future-technology': technologies which have not yet been technically proven, even though they are scientifically feasible; applied R&D on components would fit into this stage, as would bench-scale model development at laboratory levels to establish the technical viability of the technology.

For a technology to be classified under one of these stages, most of its recent applications should have reached this stage, and this list represents the results of the more detailed technical and economic analysis of the study.

Economic (In Some Locations):

- Solar water heaters, replacing electricity, or with seasonal storage and for swimming pools
- Solar industrial process heat with parabolic trough collectors or large flat-plate collectors
- Residential passive solar heating designs and daylighting
- Solar agricultural drying
- Small remote photovoltaic systems
- Small to medium wind systems

- Direct biomass combustion
- Conventional geothermal technologies (dry and flashed steam power generation, higher temperature hot water and low temperature heat)
- Tidal systems

Commercial-With-Incentives

- Solar water and space heaters, replacing natural gas or oil
- Electricity generation with parabolic trough collectors
- Non-residential passive solar heating and daylighting
- Biomass liquid fuels (ethanol) from sugar and starch feedstocks
- Binary cycle hydro-geothermal systems

Under-Development

- Solar space cooling (active and passive)
- Solar thermal power systems (other than parabolic trough collectors)
- Photovoltaic power systems
- Large-sized wind systems
- Biomass gasification
- Hot dry rock geothermal
- Geothermal total flow prime movers
- Wave energy systems

Future-Technologies

- Photochemical and thermochemical conversion
- Fast pyrolysis or direct liquefaction of biomass
- Biochemical biomass conversion processes
- Ocean thermal energy conversion systems
- Geopressured geothermal
- Geothermal magma

Renewable energy technologies, particularly hydropower, traditional biomass, solar thermal and wind, are well established in world markets (or are rapidly establishing themselves, e.g. photovoltaics), and have established industries and infrastructures (see Table

3.1.). Other renewables are fast becoming competitive in widening markets, and some have already become the lowest cost option for stand-alone and off-grid applications.

Table 3.1. Categories of Renewable Energy Conversion Technologies

Technology	**Energy Product**	**Application**
Solar energy		
Photovoltaic solar energy conversion	Electricity	Widely applied; rather expensive; further development needed
Solar thermal electricity	Heat, steam, electricity	Demonstrated; further development needed
Low-temperature solar energy use	Heat (water and space heating, cooking, drying) and cold	Solar collectors commercially applied; solar cookers widely applied in some regions; solar drying demonstrated and applied
Passive solar energy use	Heat, cold, light, ventilation	Demonstrations and applications; no active parts
Wind energy		
Water pumping and battery charging	Movement, power	Small wind machines, widely applied
Onshore wind turbines	Electricity	Widely applied commercially
Offshore wind turbines	Electricity	Development and demonstration phase
Hydropower		
	Power, electricity	Commercially applied; both small and large-scale applications
Geothermal energy		
Geotermia a bassa entalpia	Heat	Commercially applied
	Heat, steam, electricity	Commercially applied
Bioenergy		
Combustion (domestic scale)	Heat (cooking, space heating)	Widely applied; improved tech. Available
Combustion (industrial scale)	Process heat, steam, electricity	Widely applied; potential for improvement
Gasification/power production	Electricity/heat (CHP)	Demonstration phase
Gasification/fuel production	Hydrocarbons, methanol, H2	Development phase
Hydrolysis and fermentation	Ethanol	Commercially applied for sugar/starch crops; production from wood under development
Pyrolysis/production of liquid fuels	Bio-oils	Pilot phase; some technical barriers
Pyrolysis/production of solid fuels	Charcoal	Widely applied; wide range of efficiencies

Extraction	Biodiesel	Applied
Digestion	Biogas	Commercially applicable

3.2. Solar energy Technologies

3.2.1. Solar Thermal Heating and Cooling

Solar **H**eating and **C**ooling (SHC), as defined here, comprises technologies and designs for solar water heating, solar space heating and cooling, using both active technologies and passive system designs, daylighting, and agricultural and industrial process heating.

Solar water heating, including pool heating, has been commercially available for more than 30 years. While still needing further improvements, it can be considered a mature technology. Active solar space heating, which has been commercially available for almost as long, lags significantly behind in the market, primarily because of its relatively higher cost.

In recent years, systems that combine water and space heating, called combi-systems, emerged on the market and show great promise for further success. Active solar cooling was developed in the 1980s but was never able to compete economically with conventional air conditioning systems. In recent years, the combination of advanced solar cooling systems coupled with changing market conditions created an opportunity for active solar cooling to enter the market in a significant way. Other technologies are experiencing renewed interest. Although its current market share is insignificant, solar crop drying is now commercially available for specific crops in specific locations. Solar process heat for industrial processes, initially investigated in the 1980s, is once again under study.

Passive solar heating, and to a lesser degree, passive solar cooling (or perhaps more accurately, passive cooling load reduction) has also been commercially available for about 30 years. These systems can reduce the heating and cooling load by 50% with no additional cost; some systems can reach 75% heating and cooling load reduction with modest additional cost. Daylighting designs have matured to the point where they can provide significant economic benefits and are expected to become more widely used in new commercial buildings.

In addition to their capabilities to meet heating, cooling and lighting loads, SHC technologies can improve energy security and energy services at the point of end use. They can also reduce peak demand on electricity systems.

Continued RD&D on solar heating and cooling is highly justified. Solar heat is the logical successor of oil and gas used for heating. More than one-third of global energy use is for heating. Bioenergy and geothermal energy (in some geographic regions) are the main renewable alternatives in this segment of market demand. However, in coming years, bioenergy sources will also be used increasingly to generate electricity and fuels in vehicles and geothermal energy will be used to generate electricity. The implied competition for resources emphasises the importance of improving capacity to utilise solar heat.

Solar heat has a high cost-effectiveness for RD&D funding as a number of applications are already close to the market. Furthermore, use of solar heat will, as with other renewable energy sources, provide significant local and global environmental benefits while contributing to energy security, promoting employment and supporting sustainable economic development of nations.

Solar thermal collectors are already widely used in certain countries, primarily for hot water production (see Figure 3.1.). Various technologies are becoming more widely used, such as unglazed, glazed and evacuated tube water collectors, which have market shares of 30%, 50% and 20%, respectively. In principle, larger systems can be used for residential space heating and – in combination with absorption heat pumps – for cooling. However significant cost reductions are needed before the latter application will become cost-effective.

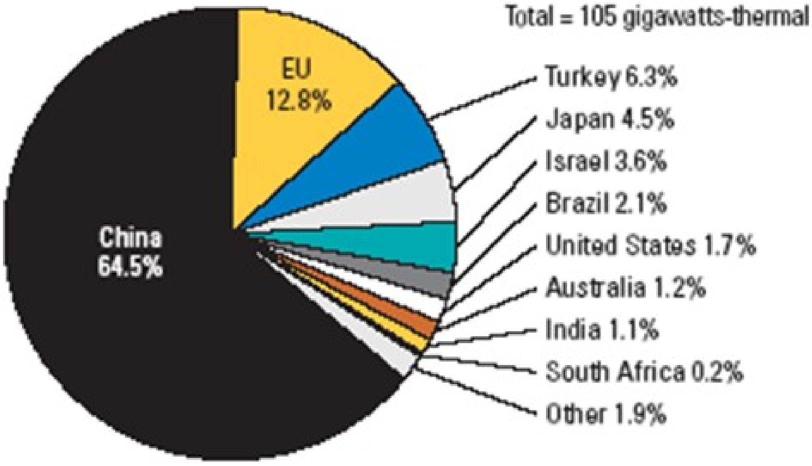


Figure 3.1. Solar Hot water Heating Capacity Existing for 2006

Current Situation and Applications: Solar thermal technologies, which provide heating and hot water for residential, commercial and industrial end uses, have a long history of commercial application. Several million hot water systems have already been sold worldwide. They have been used widely in building design and hot water heating, which are considered the easiest and most direct applications of solar energy. Solar space heating systems can be either water systems or air heating systems. The technologies are well developed for many of the applications, although more cost reductions to improve competitiveness are still being achieved. They are considered cost effective in countries with favorable climates, for example those below 40 degrees latitude, and increasingly there are new applications that are also cost effective above 40 degrees latitude.

A large variety of solar-thermal components and systems, mostly for residential applications, are available on the market. The products are reliable and show a high technical standard in the low temperature regime. However, technical and economic barriers and obstacles prevent wider use of solar thermal components and systems. Market growth is not yet stable and still is very much dependant on public support, as is often the case with other nonrenewable and renewable energy technologies.

Growth in the installation of new systems is strong, estimated at between 10 and 30 per cent per year, depending on the country concerned. Solar thermal systems have proven popular for a variety of special-purpose markets, e.g. for heating swimming pools, where there are between 1 and 2 million m^2 of collectors installed worldwide. Solar thermal systems supply hot water or cooling in hotels and other service areas such as hospitals where hot water consumption is high. There are several technologies available that provide space cooling.

Solar desalination is important in many parts of the world where fresh water for irrigation is at a premium. Solar cooking has also proven popular. There are over 450,000 solar cookers installed in India, and a further 100,000 in China. An adapted form of solar cooker can be used to dry crops. This has proven effective in northern countries such as Finland, Norway and Switzerland.

Industry and market deployment: SHC applications have a low penetration in countries where business is carried out mainly by small and medium enterprises with partly manual fabrication and no established technicalscientific RD&D divisions. There has been, however, rapid market growth in recent years for **S**mall **S**olar **D**omestic **H**ot **W**ater (SDHW) systems in countries moving towards partly automatic or semi-automatic fabrication of solar-thermal components. Over the past 20 years, specific costs of SDHW systems decreased by a factor of two. Nevertheless, “solar heat” is not yet seen as fully competitive with fossil alternatives.

RD&D in solar heating and cooling: Three key elements are required to achieve the desired boost in SHC contributions to meeting energy demands: initial government support for RD&D, information dissemination and market development. A basic justification for continued RD&D support is that this very RD&D is a basic and fundamental aspect of technology and market development.

Continued RD&D will also support the early development phase of a number of SHC technologies and bolster the solar industry, which is admittedly small in comparison to most other energy technologies.

That said, it is important to emphasise that RD&D and RD&D support are not the only criteria for creating a mature market for SHC technologies. Market stimulation is another essential element; in fact, one without the other does not provide best value for the money invested in either. Policies, economics and cultural aspects also have a significant impact on the market development for SHC.

During the past two decades, market development has been positive but this is only as a result of a few major successes. The worldwide market for glazed solar collectors has increased to the order of 10 million m^2/year (equivalent to an installed thermal capacity of ~7 000 MWth/year) during the last decade. However, outside of China, sales are the same now (about 2.5 million m^2/year) as in the early 1980s. Over the same time period, the European (EU15) market for glazed solar collectors increased to the order of 1.5 million m^2/year (~ 1 000 MWth/year), but outside Austria and Germany, sales are also the same today (about 0.3 million m^2/year) as in the early 1980s.

The cost reduction history for solar water heating systems and for the newer combi-systems shows average values of system costs (including VAT and installation) for solar domestic hot water systems (SDHW) and Solar Combi-Systems (SCS). These numbers are based on German and Austrian installations, which represent almost 75% of the European market for these systems. This learning curve demonstrates that, over the past ten years, each doubling of the market led to a 20% reduction in the installed cost.

Price reductions observed in the past for SDHW systems are now also evident for solar combi-systems. Although solar thermal systems are usually not sold in order to save money, (especially with regard to single- and double-family houses), it is interesting to note that the average price of one kWh of solar-heated water is about USD 0.19/kWh; for combined water and space heating, the price is about USD 0.37/kWh. This cost accounting was performed for a 20-year life, with 4% interest and without subsides. Even lower specific solar costs can be achieved in large-scale, centralised heating plants with collector areas larger than 100 m2. In some countries that offer subsidies, such as Germany with a present subsidy of USD 136.657 /m^2 collector area, this results in heat prices of approximately USD 0.12/kWh. In some countries, this price is close to the current price of heat generated with individual oil or gas boilers. In other countries, as is currently the case in Germany, it is still higher by a factor of two. It is interesting to examine estimates of current costs of typical SHC systems, along with an indication of their typical performance (Table 3.2).

Table 3.2. Current cost of typical solar heating and cooling systems

Technology	**Current Cost**	**Performance Indicator**
Solar Water Heating	3 100 - 7 500 USD/system	60-70% solar fraction
Solar Combi-system	17 300 USD/system	20-40% solar fraction
Solar Cooling	1.5 –3 times conventional cooling system cost	30-50% primary energy savings
Passive Heating	No additional cost	50% of the building heating load is typical
Daylighting	n.a.	n.a.

The cost/unit energy input for SHC systems is strongly dependent on site and application; this sensitivity is evident in the following figures for solar cooling. A cost assessment of the first realised projects performed in the SHC Programme showed values between USD 1900/kW of installed cooling and USD 6200/kW. This was due to large system variations in terms of size, hardware (air handling units, chillers, chilled water networks, type of backup, type of solar collector, etc.) and level of development (pilot plants, RD&D plants, or commercial projects).

Typical initial costs were 1.5 to three times higher for a solar-assisted A/C compared to conventional solutions, largely due to the extra installations (mainly solar). Cost savings depend strongly on: site (duration of cooling season, solar gains), application (number of cooling hours, coincidence between load and solar gains) and - of course - the cost of conventional energy. In most cases, annual operating costs are 10% to 50% higher for solar cooling solutions compared to conventional.

In the case of well-designed systems in the best applications, cost break-even can be achieved with subsidies in the range of USD 124/m^2 to USD 186/m^2 of collector. Cost reductions can be expected for large systems by standardised solutions with reduced design effort, standardised and optimised control. Further cost reductions are also expected for large collector fields with increased experience on the construction of large collector fields. Regarding design of the system of solar cooling, well-designed systems should be able to meet about 70% to 90% of the cooling load, which is possible in most cases, although thermal storage may be needed for some hours in some cases (e.g., diurnal mismatch between gains and load). Primary energy savings in the range of 30% to 50% can be achieved.

Worldwide contribution of solar thermal heat to the total energy supply is significantly underestimated. According to the IEA Solar Heating and Cooling Programme's 2005 publication Solar Heating Worldwide 2003, an overall capacity of 92.7 GWth of solar thermal collectors was installed in 2003. Installed capacity in the EU15 was approximately 10 GWth.

Despite this considerable capacity, most of solar thermal systems are used for swimming pool heating, domestic hot water preparation and, to some extent, for space heating. Use of solar thermal energy in large-scale residential buildings, for cooling and industrial applications or drying, is currently insignificant.

The target set in the European Commission (EC) 1997 White Paper on renewable energy is 100 million m^2 of solar collector area installed by 2010. This target clearly will not be reached. However, it is apparent that solar thermal energy has the potential to meet a significant portion of the heating and cooling demand in the residential sector and make a large contribution to the energy supply of the commercial and tertiary sector. Of course, it is equally important that better efficiencies are used to reduce these heating and cooling demands.

To reach the EC's target and retain the leading technological position in the field of solar thermal technology, an ambitious fundamental and applied RD&D programme is required. The objective should be to develop competitive, advanced SHC systems that can cover 5% to 10% of the overall low-temperature heat demand of IEA member countries by 2020.

Benefits: One of the main benefits of solar thermal systems is that there are no emissions. This is particularly beneficial for solar cooking as it avoids indoor air pollution, a major health concern in developing countries. Solar cooking is also important in regions where there is increasing scarcity of firewood or other options. However, one of the limits of solar cookers is that they can only supplement, and not fully replace, other cooking systems. It is estimated that they can save a third to a half of conventional fuel used for cooking.

Solar systems can be installed in most types of buildings throughout the world and they can easily be installed during renovation of existing buildings. Solar desalination is important because around 30,000 square kilometres of land are taken out of use annually due to salt levels in the ground being too high.

Solar district heating can be an attractive way of supplying solar heat to existing district heating systems. An advantage is that they can be combined with other sources of energy. By including seasonal storage, as much as 50-70 per cent of the heat can be supplied by solar energy in countries with moderate climates.

Potential: Growth remains strong in many regions. In Europe, for example, the market is expected to expand by around 20 per cent per year. The market is also strong in developing countries, and is particularly buoyant in China. The potential for solar crop drying is high. The potential for solar drying worldwide is estimated to be between 600-900 PJ. The expanded use of electric heat pumps also shows good potential.

Solar heating can be constrained because of the mismatch between demand and supply (which is available when there is sun), thus requiring some form of storage. There are a variety of storage systems available, and a new generation of storage technologies are at the demonstration stage. There is still strong potential for cost reductions for hot water and space heating systems, which will make them even more competitive.

Cost reductions of up to 50 per cent for collections and around 30-40 per cent for total systems could be achieved by expanding manufacturing facilities in developing countries.

Additional RD&D priorities: A comprehensive and ambitious applied RD&D programme is needed to develop competitive advanced SHC systems that would eventually be able to cost-effectively provide 5% to 10% of overall low-temperature, heat demand of the IEA member countries. As suggested above, there are four key areas in which RD&D efforts are most needed: advanced materials and components; advanced solar heating and cooling systems; building and design integration; and standards, regulations and test procedures. Specific aspects of each area are discussed in more detail below.

1. Advanced materials and components: High performance and cost-efficient materials for improved solar thermal systems, fundamental and applied research is needed to develop:
    - Cost-effective optical coatings on surfaces interacting with solar irradiation in order to enhance reflection, transmission or absorption of light in highly effective ways.
    - Low-cost, anti-reflective and self-cleaning glazing materials (e.g., new synthetics, embossing of suitable micro-structures into the surfaces of panels and tubes).
    - Material research is needed on the thermal side of solar thermal energy conversion:

    - Materials and components are needed that can withstand high stagnation temperatures of high-efficiency solar thermal collectors without decreasing efficiency in the required temperature range, or breaking down and thereby shortening the 20-year service life
    - Plastic materials for collectors, particularly plastics with high thermal and optical performance, could significantly reduce the costs of solar thermal systems.
    - To address the issue of solar thermal energy storage, there is a need for advanced insulation materials and for energy storage materials with a higher energy density than water. Promising technologies are based on phase change materials or thermo-chemical storage processes (e.g., sorption). Specific RD&D needs are described below.
2. Advanced solar thermal components: There is a need for further innovation in the design of collectors, specifically:
    - Advanced flat-plate collectors specifically designed for roof and façade integration.
    - New collectors for medium-temperature applications (up to temperatures of approximately 250°C) are necessary for new and challenging applications such as solar cooling and solar heat for industrial processes.
    - **P**hoto**V**oltaic-**T**hermal (PVT) collectors.
3. Thermal energy storage: The potential for solar thermal applications in the housing sector and in industry will increase dramatically once suitable technical solutions are available to store heat for the medium (daily) to longer (seasonal) term. Such advanced storage systems could utilize chemical and physical processes to reduce total storage volume and related costs. The general aim should be to develop materials, components and systems that allow a reduction of storage volume by at least a factor of three compared to water. With current Phase Change Materials (PCM), only a factor of 1.5 to two can be expected, relative to hot water systems. Water tanks will achieve a good method for heat storage. However, when it comes to high solar fraction for solar homes, they show limits due to the required size and the heat losses. New materials and new types of storage concepts are necessary. These could be based on PCMs or chemicals, or on a combination of water tanks and those materials adequately encapsulated. PCM materials can also be incorporated into structural

elements of buildings. In order to produce cold when the sun is available and deliver cold water on demand, solar assisted air conditioning and cooling systems need both hot and cold storage. This is another promising application for PCM materials.

3.2.2. Photovoltaics

Photovoltaic (PV) technology permits the transformation of solar light directly into electric current. PV systems can deliver electric energy to a specific appliance and/or to the electric grid. PV has the potential to play an important role in the transition towards a sustainable energy supply system of the 21st century and to cover a significant share of future electricity needs. In addition, the technology could improve security of future energy supply, provide environmentally benign energy services and enhance economic and social welfare. In combination with other renewable energy technologies and energy efficiency, PV technology is becoming a key technology for the future.

In 1992, installed capacity of photovoltaics amounted to 110 MW. By 2003, the figure had risen to 1809 MW, with three countries accounting for 85% of total installed capacity: Japan (860 MW), Germany (410 MW) and the United States (275 MW). Although PV capacity saw remarkable growth rates in 2003, PV electricity production from grid-connected systems remained relatively low at 1300 GWh, accounting for only 0.007% of total electricity production and 0.05% of total renewable electricity production in the world.

The photovoltaic (PV) market has grown extensively since 1992. RD&D efforts, together with market deployment policies, have effectively produced impressive cost reductions: every doubling of the volume produced prompted a cost decrease of about 20%. But market deployment is concentrated: Japan, Germany and the United States account for over 85% of total installed capacity. PV still requires substantial RD&D investments, as well as deployment supports, to gain market learning. In the near term, RD&D efforts will focus on improving the balance-of-system components for both grid connected and stand-alone applications. Even with these supports, PV is not expected to be generally competitive until after 2020 – although it will continue to compete well in a growing range of market niches in which the cost of deployment supports is moderate.

PV offers several advantages including:

- Complementarities with other energy sources, both traditional and renewable.

- Flexibility in terms of implementation. PV systems can be integrated into consumer goods or into buildings, installed as separate mobile or non-mobile modules, or used in central electricity generating stations.
- Environmental advantages. PV produces electricity with no greenhouse gas or other emissions and no noise.

Even though the amount of electricity produced using PV has increased rapidly year after year, it is still at a very low level compared to other renewables such as wind or biomass. The major barrier preventing uptake in today's market is the capital cost of PV, which makes the electricity produced too expensive for many applications. The industry must become more competitive; it needs to develop more efficient manufacturing processes and conversion devices. The regulatory framework often hinders installation and effective standardization would yield many advantages. Current markets perceive the technology as being suitable for niche applications, but not for general use. However, as various countries (e.g., Japan and Germany) reach GW levels of installed capacities, PV should gain wider recognition and acceptance. Fully coordinated research efforts could help overcome some of these barriers, but all stakeholders must also engage in other actions to realise broader deployment.

Current Situation and Applications: The direct relation between light and electricity was demonstrated by Antoine Henri Becquerel in 1839. However, it was not until the development of diodes in 1938 and transistors in 1948 that the creation of a solar cell became possible. The foundation for modern PV technology was laid in the early 1950s, when researchers at Bell Telephone Laboratories discovered and developed crystalline silicon (c-Si) solar cells, which they patented for the first time in 1955 and successfully used in space applications in 1958. Despite early attempts to commercialise silicon solar cells on a larger scale, the technology was not developed enough to warrant large-scale production until the 1980s.

Since then, laboratory and commercial development has progressed steadily, creating a portfolio of available PV technology options at different levels of maturity - and experience that can be expressed by a robust learning curve (price reduction vs. cumulative production of commercial PV technology).

Photovoltaic (PV) systems use semiconductor materials to convert sunlight directly into electricity. They can be used separately or in hybrid form, in combination with another generating option such as other renewables or fossil fuels. The market for photovoltaics is expanding at 20-35 per cent per year. Costs have dropped to between one-third and one-fifth of 1980 levels. Total installed capacity is over 800 MW worldwide and, in 1999 alone, PV module production stood at 200 MWp worldwide.

As stepping-stones to a large-scale power market, PV is now cost effective in many specific-purpose applications, such as telecommunications, lighting, water pumping, leisure and signalling. Applications in hospitals can be valuable in regions where conventional energy supply is unreliable. Solar-based refrigeration is important for transporting medical supplies (particularly in rural areas) but also for transporting refrigerated goods in IEA countries. For example, in the United Kingdom, the success of a prototype trailer that uses solar power for refrigeration has led to one UK company commissioning two more trailers.

These are used to transport perishable foods for a nationwide supermarket chain. One of the main benefits is the reduced emissions and noise from avoiding diesel generators for cooling. A recent application, which shows good promise worldwide, is a PV system that floats and purifies water in landlocked areas.

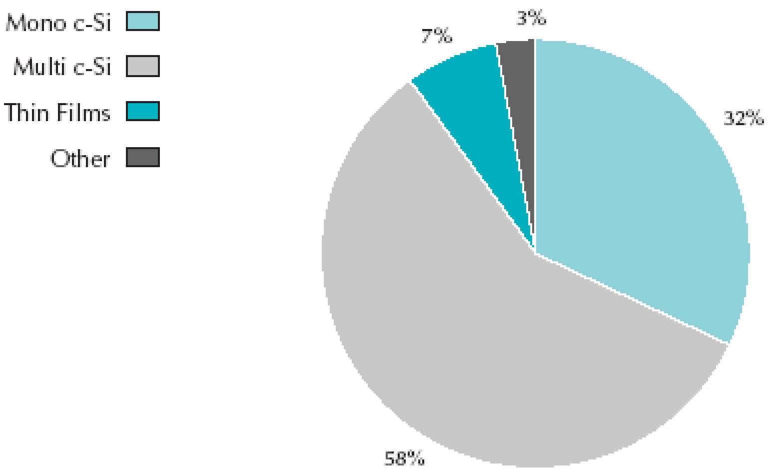
Solar photovoltaics (including modules, system components, and installation) will grow from a \$29.6 billion industry in 2008 to \$80.6 billion by 2018. Annual installations reached more than 4 GW worldwide in 2008, a fourfold increase from four years earlier, when the solar PV market reached the gigawatt milestone for the first time.

Photovoltaic modules: A PV system consists of a module (array of cells generating the electricity) and a **B**alance-**O**f-**S**ystem (BOS) including (if applicable) the cabling, battery, charge controller, and DC/AC inverter, as well as other components and support. Most systems are the “flat-plate” variety, which operate by collecting solar energy directly on the module. Flat-plate systems are usually static (i.e., having a fixed orientation) but they may also use sun-tracking components. A distinctly different type of system, known as PV concentrators, combines sun-tracking with an optical system to concentrate sunlight onto a small-area, high-efficiency solar cell.

As indicated above, PV modules are generally divided into two broad categories:

- Wafer-based crystalline silicon (c-Si).
- Thin films, which include thin-film silicon, copper-indium/gallium-selenide/sulphide (CIGS), amorphous silicon (a-Si) and cadmium telluride (CdTe).

Wafer-based crystalline silicon is currently the dominant technology for several reasons: it is widely available; it has proven reliability; and it is well understood – indeed, it is founded on the knowledge and technology originally developed for the electronics industry. Crystalline silicon modules (mono crystal or multi-crystalline) are typically produced by growing ingots of silicon, in a manner similar to that used for electronics devices. The ingots are sliced to make wafers, which are then processed into solar cells and electrically interconnected. The final step involves encapsulating strings of cells to form a module. The fabrication process creates challenges for the PV industry. First, it is necessary to begin with very high quality feedstock but overall silicon utilisation is still relatively low as a large fraction of the silicon is lost during processing. Thus, material costs for c-Si wafers are high compared to thin-film modules. In addition, manufacturing is often not yet optimally automated. Finally, current silicon feedstock production is energy intensive. These factors lead to a module energy payback time of several years, although it is now substantially lower than the module lifetimes of 20 to 30 years. In Figure 3.3., PV production Technologies has been given.



Source: EC, 2005.

Figure 3.3. Production by technologies, 2003

In contrast, thin-film modules are produced by coating and patterning entire sheets of substrate, usually glass or stainless steel, with micron-thin layers of conducting and semiconductor materials, followed by encapsulation. This process can be highly efficient in materials utilisation, has relatively low labour requirements, and uses comparatively little energy from start to finish.

Total area stable efficiencies of thin-film modules are in the range of 5% to 17%, which are, in principle, high enough to enable large-scale use. Nevertheless, it is still critical to improve efficiency without increasing costs in order to reduce module manufacturing costs per Wattpeak.

Estimates suggest that efficiencies of current technologies could be increased to 15% to 20%, or slightly higher (further increases are possible but would require a fundamentally different approach). The range of commercial module efficiencies is expected to increase to 10% to 30% - or higher - by 2030, while also fulfilling cost reduction requirements. These figures may refer to very different technologies and applications, such as polymer-based module "foils" or super high-efficiency, sun-tracking concentrator systems.

Even though its reliability and performance underpin crystalline silicon's current domination of the market (a 90% share), there is still potential for further improvement in terms of manufacturing costs and efficiency. The learning curve of PV modules has been fully determined by c-Si in the past; this driving force is expected to continue for the next 10 to 15 years.

In contrast, the market share of thin films has remained at very modest levels over the past decades - even decreasing from 15% in 1995 to 5% today as c-Si production rose. However, as an emerging technology, thin films have important potential to extend the PV learning curve beyond the limits of c-Si technology. Existing thin films (e.g., amorphous/microcrystalline silicon or CIGS) could eventually compete with c-Si, but further development and scaling up of manufacturing is necessary. Thin-film technologies also have the advantage of allowing for specific applications such as flexible modules, semi-transparent modules, etc. To realise the potential of thin films, the PV industry and research sectors must collaborate closely to solve both fundamental and technological problems. Given the progress to date, the market share of thin-film technologies is expected to increase after 2010.

The current investment necessary for production equipment for wafer-based c-Si is approximately USD 0.6/W of annual production capacity; additional investments for building, infrastructure, electricity and gas supply, waste management and recycling, etc. bring the total investment requirement to USD 1.9/W. This represents approximately USD 93 million for a 50 MW manufacturing plant.

To date, no active manufacturing plant has successfully proven the cost-benefit potential of thin films in practical terms. Both processes and equipment remain at an immature stage, and material and energy costs are not yet optimised. The major cost element for thin films is the capital for equipment and materials. Thus, reducing material costs will be key to achieving low overall module costs in the long term.

There is a third technology that captures a small share of the commercial PV market. Concentrator technologies are made up of very high-efficiency, small-area solar cells used in combination with large-area, optical concentrators. Although the solar cells may be expensive per unit area, the overall technology provides an important alternative route to low generation costs. Concentrator systems effectively substitute expensive solar cells elements with less expensive optical elements. Higher total system costs – associated with optics, tracking, cooling, etc. - are compensated for by higher efficiency. However, because of their reliance on direct solar radiation, application of concentrator systems is restricted to clear sky locations.

Benefits: The popularity of PV systems springs from many positive attributes. They have been most successful in stand-alone applications, representing up to 80 per cent of total installations. They are highly reliable, with few breakdowns and are easy to use. They have few detrimental effects on the environment, with minimal visual impact. Their modularity makes them flexible and easy to increase capacity depending on demand requirements. Installation is quick and easy and they can be arranged to meet a wide range of power requirements. PV systems can be integrated into building materials (for example, roofing tiles or walls), thus reducing both capital and installation costs. In rural areas of developing countries, PV systems have proven important, as shown above, for transporting medical supplies.

Hybrid systems offer the benefit of continuous electricity generation, which is useful in stand-alone projects such as telecommunications, remote housing or tourist facilities. Hybrid systems are also useful on small islands or for village power.

Operating and maintenance costs are generally quite low, as PV systems are highly reliable. PV can be important in developing countries where the electricity infrastructure is poor or non-existent. The flexibility of PV has led to its increased use as roofing or other building integrated system, thus reducing overall cost.

Potential: Some estimates suggest that total capacity could reach almost 12000 MWp by 2010. Stand-alone applications will continue solid growth according to all assessments. Some consider that by 2010 the total installed capacity for grid purposes worldwide might be 4001000 MWp. A recent market assessment of the potential for using solar photovoltaic technology in Bangladesh concluded that half a million rural households could afford solar home systems as a source of electric power. It is estimated that only 15 per cent of rural households have received grid electricity in Bangladesh. PV could therefore be used to provide energy services currently not available. The global potential is high, considering that PV systems could be used in most of the 400 million households currently without electricity.

Technology applications: PV technology and applications are characterised by their modularity: PV can be implemented on virtually any scale and size (see Table 3.3.). Overall efficiency of systems available on the market varies between 5% and 15%, depending on the type of cell technology and application. The expected life span of PV systems is between 20 and 30 years. The solar modules are the most durable part of the system, with failure rates of only one in 10,000 per year. Some components, e.g., the inverter and battery, must be replaced more regularly.

Experts expect c-Si to continue dominating the market in the coming years but also predict that thin-film solar cells will become considerably less expensive in the medium to long term. It is certain that different cell technologies can exist side by side. Some applications require high efficiency in a small space (c-Si); others need less expensive material to cover a larger area (thin-film cell technologies). Therefore, speaking of different cell generations does not adequately reflect current understanding of the wide range of photovoltaic technologies.

Table 3.3. Examples of PV applications according to size (*Source: NET Ltd., Switzerland)*

Size class	Applications
up to 10W	Pocket calculators, radios, remote wireless sensors, small chargers, electric fences
10W to 100W	Small illumination systems, call boxes, traffic signals, parking meters, navigation lights, small communication systems, weather stations, solar home systems, medical refrigeration, cathodic protection, small stand-alone systems for isolated huts
0.1kW to 1kW	Medium-sized pumping systems and irrigation systems, desalination plants, propulsion of smaller recreation boats, stand-alone systems for isolated buildings, small rooftop systems, small hybrid systems
1kW to 10kW	Medium-sized, grid-connected building and infrastructure-integrated systems; large stand-alone systems for isolated buildings; medium-sized hybrid systems
10kW to 100kW	Large grid-connected systems -either building- and infrastructure-integrated or ground-based
0.1MW to 1MW and above	Very large grid-connected systems - either building-integrated or ground-based

Stand-alone or off-grid PV systems are particularly well suited for areas that are not easily accessible, that have no access to electricity mains, or where grid connection is uneconomic or unnecessary. A typical stand-alone system consists of a PV module or modules, a battery and a charge controller. An inverter may also be included to convert the Direct Current (DC) generated by the PV modules into the Alternating Current (AC) required by many appliances.

Stand-alone system applications can be subdivided into industrial (telecommunications, water pumping, street illumination, etc.) and rural domestic (isolated housing). PV systems can also be connected to local electricity networks. Electricity generated can be used immediately (e.g., in homes or commercial buildings) and/or can be sold to an electricity supply company. When the solar system is unable to provide the electricity required (e.g., at night), power can be bought back from the network. In this way, the grid acts as a kind of "energy storage system" for the PV system owner, eliminating the need for battery storage. Grid-connected systems can be subdivided into building-integrated applications and grid-support power.

Examples of the price structure for flat-roof, sloped-roof and façade-integrated PV systems in Western Europe are shown in Table 3.4. Prices vary according to the maturity of the local market and specific conditions. For example, installation costs are now relatively low in Germany due to the 100000 Roofs Programme and the Renewable Energy Sources Act. Furthermore, system prices vary significantly depending on whether the system is part of a retrofit or is integrated into a new building.

Table 3.4.. Typical prices (USD) of small (1 kW to 5 kW) building-integrated photovoltaic systems in urban areas of Switzerland, 2002

Cost Category USD/kW	**Flat Roof**		**Sloped Roof**		**Facade**	
	min	**max**	**min**	**max**	**min**	**max**
Project development, engineering and other costs	400	1 800	400	1 800	500	1 800
Modules	3 300	4 500	3 300	5 500	3 300	6 000
Inverters	500	800	500	800	500	800
Cabling	250	350	300	500	400	600
Module support structure	350	450	400	600	600	1200
Mounting and installation	1 200	1 600	1 400	2 000	2 000	2 500
Total Investment	6 000	9 500	6 300	11 200	7 300	12 900

RD&D and market deployment: In recent years, market deployment of photovoltaics experienced very dynamic growth rates exceeding 30% per year, mainly due to supportive frameworks in a limited number of countries. At the same time, rapid development in technology and manufacturing development triggered strong investments by the PV industry. In fact, RD&D efforts by the private sector clearly surpassed public expenditures; it is estimated that the private sector now bears a two-thirds share of total photovoltaic RD&D. In addition, the largest manufacturers are rapidly extending their production capacities.

Still, it is crucial to strengthen public RD&D efforts in order to adequately balance market deployment activities and to continue supporting development on the technology side, with the aim of realising potential for further substantial cost reductions. Although it is difficult to determine on an absolute scale, it is clear that an adequate balance between RD&D and market deployment will maximise the learning rate. Public RD&D funding is vital at the early stages of technology development. But public support is also needed where market failures arise to avoid situations in which cost signals are not transparent and market access is restricted by existing technologies and infrastructure.

3.2.3. Solar Thermal Electric Power

Solar thermal power is one of the main candidates to provide a major share of the renewable clean energy needed in the future. The appeal of solar radiation is evident in that it is:

- The largest renewable resource on Earth. Solar thermal power is logically one of the main candidates to provide a major share of renewable, clean energy needed in the future.
- More evenly distributed in the sun belt of the world than wind or biomass, allowing for more site locations.
- Among the most cost-effective renewable power technologies and the lowest-cost solar electricity in the world. Power generation costs are expected to be in the range of USD 0.075 kWh to USD 0.19/kWh, promising cost-competitiveness with fossil fuel plants in the future.
- A proven and demonstrated technology. More than 100 years of accumulated operating experience demonstrate the soundness of the concept. Since the earliest plant was installed in 1985 (California, USA), nine solar thermal power plants (of the parabolic trough type) have fed more than 8 billion kWh of solar-based electricity into the California grid.

Regarding technical features, the conversion path of all concentrating solar power technologies relies on four basic elements: concentrator, receiver, transport-storage, and power conversion (Figure 3.4.). The concentrator captures and concentrates solar radiation, which is then delivered to the receiver. The receiver absorbs the concentrated sunlight, transferring its heat to a working fluid. The transport-storage system passes the fluid from the receiver to the power-conversion system; in some solar-thermal plants a portion of the thermal energy is stored for later use. Several solar thermal power conversion systems have been successfully demonstrated including Rankine, Brayton, combined or Stirling cycles.

Three emerging solar thermal power generation concepts – namely the parabolic trough (or ‘solar farm’); the solar central power receiver (or ‘power tower’); and the parabolic dish system – will be described in more detail.

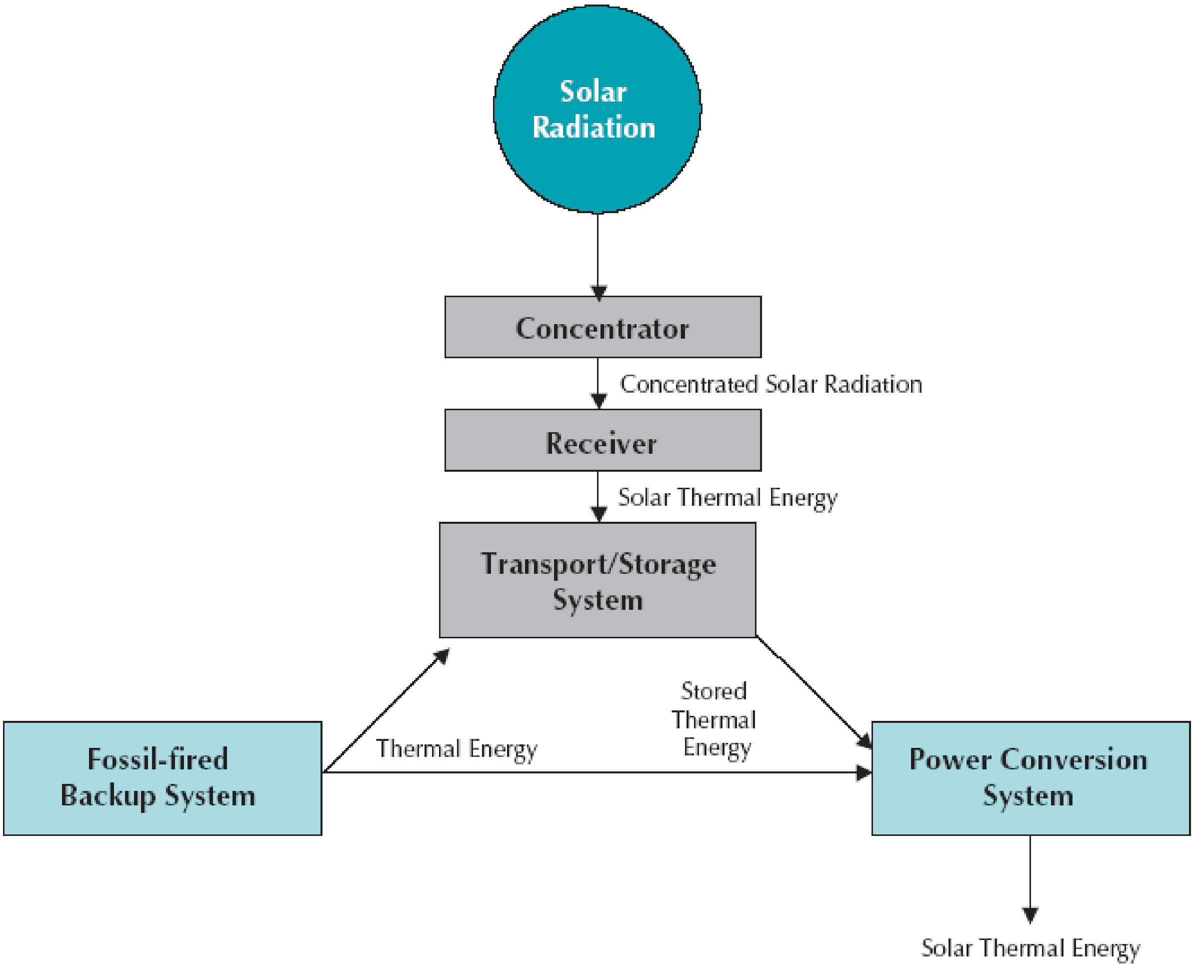


Figure 3.4. Conversion path from solar radiation to solar electricity

Each technology can be integrated into conventional thermal cycles as “a solar burner” in parallel to a fossil burner. This makes it possible to provide thermal storage or fossil fuel backup firm capacity without the need for separate back-up power plants and without stochastic perturbations of the grid.

These features make Concentrating Solar Power (CSP) technologies a strong candidate for large-scale emissions reduction at reasonable cost. CSP technologies are appropriate for a wide range of applications, including dispatchable central-station power plants (in which they can meet peak-load to near-base-load needs of a utility) and distributed modular power plants (for both remote and grid-connected applications). The availability of storage and the ability to share generation facilities with biomass suggest good potential to provide a replacement for high-capacity, factor fossil fuel plants.

It is believed that CSP can contribute significantly to a truly sustainable energy system and the sector has adopted a vision to see this achieved in the medium to long term in Europe. The European Commission (EC) thus adopted a coordinating action, the European concentrated Solar Thermal Road-Mapping (ECOSTAR), to harmonise the fragmented research methodology previously in place in Europe – which led to competing approaches on how to develop and implement CSP technology. Cost-targeted innovation approaches, as well as continuous implementation of this technology, are needed to realise cost-competitiveness in a timely manner.

Three types of CSP technologies support electricity production based on thermodynamic processes: parabolic troughs, parabolic dishes and solar central receivers. The cost of power generated with these up to-date technologies is between USD 0.10/kWh and USD 0.15/kWh. Current RD&D efforts concentrate on parabolic trough technology. To achieve progress, much larger resources are needed than what is currently offered in public program. Optimal conditions for CSP are an arid or semi-arid climate, limiting its usefulness to southern Europe, north and southern Africa, the Middle East, western India, Western Australia, the Andean Plateau, north-eastern Brazil, northern Mexico and the US Southwest.

Current technology status: Concentrating solar power systems can be sized for village power (10 kW) or grid-connected applications (up to 100 MW). Some systems use thermal storage during cloudy periods or at night. Others are combined with natural gas and the resulting hybrid power plants provide high-value, dispatchable power. These attributes, along with “world record” solar-to-electric conversion efficiencies, make concentrating solar power an attractive renewable energy option in the southwest United States and other sunbelt regions worldwide.

For each of the three technologies discussed in the preceding pages, various designs and configurations exist. The amount of power generated by a CSP power plant depends on the amount of direct sunlight. As with concentrating photovoltaic concentrators, these technologies use only direct-beam sunlight rather than diffuse solar radiation.

The parabolic trough or 'solar farm' consists of long parallel rows of identical concentrator modules, typically using trough-shaped glass mirrors. Tracking the sun from east to west by rotation on one axis, the trough collector concentrates the direct solar radiation onto an absorber pipe located along its focal line. A heat transfer medium, typically oil (at temperatures of up to 400°C), circulates through the pipes and evaporates water. The resulting steam drives the steam turbine generator of a conventional power block. Individual commercial plants will be sized from 50 MW to 200 MW to produce electricity. To date, the only commercial-scale projects employing this specific technology were installed in California, USA, between 1984 and 1990. In total, 354 MW of solar trough plants were constructed, and remain in operation (Figure 3.5).

Figure 3.5. Solar parabolic through concentrators (Solar Farm)

The solar central receiver or 'power tower' is surrounded by an array of two-axis tracking mirrors, called heliostats, that reflect direct solar radiation onto a fixed receiver located on the top of the tower (see Figure 3.6.). Within the receiver, a fluid – water, air, liquid metal and molten salt have been tested – transfers the absorbed solar heat to the power block, where it is used to heat a steam generator. Advanced high temperature power tower concepts are now under investigation, which heat pressurised air up to more than 1000°C. The hot air is then fed into the gas turbines of modern combined cycles. Early power towers utilised steam as the heat transfer fluid; current designs utilise molten nitrate salt because of its superior heat transfer and energy storage capabilities. Current European designs use air as the heat transfer medium because of its high temperature and its good handling characteristics.

Figure 3.6. The solar central receiver (Power Tower/Solar Tower)

Parabolic dish systems consist of a parabolic-shaped point-focusing concentrator, in the form of a dish that reflects solar radiation onto a receiver mounted at the focal point. These concentrators are mounted on a structure with a two-axis tracking system to follow the sun. Collected heat is typically utilised directly by a heat engine mounted on the receiver. Stirling and Brayton cycle engines are currently favoured for decentral power conversion; central Rankine cycles are being studied for use in large fields of such dishes. Projects of modular systems have been realised with total capacities up to 5 MWe. The modules have maximum sizes of 50 kWe and have achieved peak efficiencies of up to 30% net (Figure 3.7.).

Figure 3.7. Parabolic dish type concentrators

The inherent advantage of CSP technologies is their unique capacity for integration into conventional thermal plants. Each technology can be integrated as “a solar burner” in parallel to a fossil burner into conventional thermal cycles. This makes it possible to provide thermal storage or fossil fuel backup firm capacity without the need for separate back-up power plants and without stochastic perturbations of the grid.

With a small amount of supplementary energy from natural gas or any other fossil fuel, solar thermal plants can supply electric power on a firm, secure basis. Thus, solar thermal concepts have the unique capability to internally complement fluctuating solar burner output with thermal storage or a fossil back-up heater. This makes solar thermal systems the only renewable power plants that will neither cause grid perturbations nor disturb the operation of other existing fossil plants within the entire power park.

Current CSP technology systems are implemented in the cost range of USD 0.19/kWh to USD 0.25/kWh. In the conventional power market, CSP competes with mid-load power in the range of USD 0.037/kWh to USD 0.05/kWh. Sustainable market integration, as different scenarios predicted, can only be achieved if costs can be reduced to competitive levels in the next 10 to 15 years. Competitiveness is affected not only by the cost of the technology itself, but also by potential price increases of fossil energy and by the internalisation of associated social costs, such as carbon emissions. Therefore, it is assumed that in the medium to long term, competitiveness will be achieved at a level of USD 0.05/kWh to USD 0.075/kWh for dispatchable mid-load power.

Estimates suggest that approximately half of the cost-reduction potential for CSP will be attributed to scale-up to larger plant sizes and volume production effects; the other half will be attributed to technology RD&D efforts. Scenario approaches estimate cost-reduction potential and the total market incentives needed to achieve full compositeness with conventional choices. However, they do not help to identify specific innovations that may enable these reductions.

A recent ECOSTAR evaluation analysed current costs and the total cost-reduction potential of CSP technology. In addition, all systems labelled as ‘technical innovations’ were identified and defined by a component cost and performance estimate to calculate the levelised electricity cost (LEC). It found that current investment and generation cost data for each of the reference CSP systems (Figures 17 and 18), although relatively close, vary due to different levels of maturity in the technology and different technological approaches. The costs range from USD 0.21/kWh to USD 0.22/kWh (for a parabolic trough system of 50 MWe units that uses thermal oil as a heat transfer medium) and from USD 0.24/kWh to USD 0.35/kWh (for smaller pilot scale systems of up to 15 MWe). Assuming that several of the smaller systems are built at the same site to achieve a power level of 50 MW and benefit from similar O&M efforts as the larger plants, the LEC estimates of all of the systems would range between USD 0.19/kWh and USD 0.25/kWh.

One significant exception is the hybridised system, in which solar energy is integrated into a gas turbine/combined cycle. Currently, this technology provides a solar capacity factor of only 11% and requires significant fossil fuel (20% to 25% annual solar share depending on load curve). However, it offers an LEC of less than USD 0.11/kWh for the hybrid operation (equivalent to USD 0.17/kWh for solar LEC). Thanks to the low specific investment cost of the gas turbine/combined cycle – coupled with high efficiency – the system is especially attractive for hybrid operations. Further development of the receiver technology would increase the solar share significantly in the future.

Current RD&D: As already mentioned above, RD&D efforts play a major role in both scaling up technology and in achieving further cost reductions for CSP systems. The evaluation of ECOSTAR identified major cost reduction drivers for each of the considered reference systems (Figures 17 and 18), as well as the potential impact of technical innovations. As mentioned, all systems labelled as 'technical innovations' were identified and defined by a component cost and performance estimate to calculate the levelised electricity cost (LEC). For example, the utilisation of thin glass mirrors in parabolic trough collectors has the following impacts (the first parameter value listed is the pessimistic estimate; the second is the optimistic estimate):

- Mean reflectivity is left unchanged at 0.88 / increases to 0.89.
- Specific investment costs are reduced to 95% / 90% of the reference value.
- O&M equipment cost percentage is increased to 1.1% / left unchanged at 1%.

These figures are used in the annual calculation model to define boundary values for the LEC reduction. The evaluation combined the most promising options to estimate the overall cost-reduction potential. Based on the limited number of approaches suggested in the scope of this study, one could expect cost reductions of 25% to 35% due to technical innovations and scaling.

Additional RD&D priorities: The relatively small difference in investment and generation costs between the CSP technologies makes it difficult to define RD&D priorities based on technology (e.g., trough vs. towers). However, various innovation aspects have different impacts on LEC reduction for the seven systems investigated in the ECOSTAR evaluation.

The innovation potential with the highest impact on CSP cost reduction was identified for each technology.

Summarising the detailed findings for individual systems, it is clear that improvements in the concentrator performance and cost have the most dramatic impact on LEC figures. As the concentrator is a modular component, it is possible to adopt a straightforward strategy that couples development of prototypes and benchmarks of these innovations in parallel with state-of-the-art technology – in real solar power plant operation conditions. Modular design also makes it possible to focus on specific characteristics of individual components, including reflector materials and supporting structures, both of which would benefit from additional innovation.

New reflector materials should be low cost and have the following traits:

- Good outdoor durability.
- High solar reflectivity (>92%) for wave lengths within the range: 300 nm to 2 500 nm.
- Good mechanical resistance to withstand periodical washing.
- Low soiling co-efficiency (<0.15%, similar to that of the back-silvered glass mirrors).
- New supporting structures should fulfil the following requisites:
- Lower weight.
- Higher stiffness.
- More accurate tracking.
- Simplified assembly.

Scaling to larger power cycles is an essential step for all technologies (except for parabolic trough systems using thermal oil, which have already undergone scaling in the nine solar electric generation stations (SEGS) in California starting at 14 MWe and ending at 80 MWe).

Scaling reduces unit investment cost, unit operation and maintenance costs, and increases performance. The integration into larger cycles, specifically for power tower systems, creates a significant challenge due to their less modular design. Here the development of low-risk scale-up concepts is still lacking.

Storage systems are a second key factor for cost reduction of solar power plants. Development needs are very much linked to the specific system requirements in terms of the heat-transfer medium utilised and the necessary temperature. In general, storage development requires several scale-up steps linked to an extended development time before market acceptance can be achieved. A particular challenge lies in the development of storage systems for high pressure steam and pressurised, high temperature air, which would lead to a significant drop in electricity costs.

Requirements for storage systems are:

- Efficiency in terms of energy and exergy losses.
- Low cost.
- Long service life.
- Low parasitic power requirements.

In many cases, higher temperatures lead to higher system performance. However, the current status of receiver technology does not exploit the full performance potential. Significant improvements in the performance of high temperature receivers are possible, whereas potential for performance improvements in the temperature range below 400°C is relatively small (cost improvements are possible).

Current Situation and Applications: High-temperature solar thermal power systems – also known as concentrating solar power – to produce electricity, and to some extent hot water, are showing good promise. These largescale systems are on a path to becoming cost effective. Plants in operation are achieving costs of approximately US$ 0.12/kWh, which are the lowest of any solar technology. The technology can also be combined in hybrid form (solar thermal plants coupled with diesel generators), achieving costs of around US$ 0.08/kWh.

It is important that many entities with different expertise and a variety of research institutions should be involved in RD&D projects in this field. Further expertise is required in the following areas:

- Large companies from the power sector that are capable of – and have experience in – leading engineering, procurement and construction (EPC) contracts could contribute better market knowledge and address more thoroughly the question of solar system integration with the power cycle.
- Companies specialised in glass, reflectors, light weight structures, drives, outdoor plastic etc. could provide expertise in concentrators.
- The chemical industry could support the development of improved high temperature fluid (HTF) or storage media.
- Large construction companies could assist in designing and building storage containers that are able to handle and transport hot fluids.

- Companies specialised in mass production and logistics (such as car manufacturers) could optimise production processes and minimise manufacturing costs.
- Technical supervising companies could suggest strategies to achieve a high quality control to reduce risks specifically in the scaling process.

Benefits: The amount of RD&D funds dedicated to CSP was small compared to other renewable energy technologies such as wind, photovoltaics and biomass. However, the funds have been sufficient to support a new start-up of CSP technology, for example, in Europe (specifically in Spain and Italy). Several hundred MWs of installed capacity appear likely by 2010. If, as desired, the cost reductions triggered by technical innovations are to pay off their full potential in the next 15 years, an increase in RD&D efforts should take place.

The main benefit of solar thermal power technologies is that they can provide dispatchable power for peak or intermediate loads. These technologies can also be used in distributed, stand-alone applications and are suitable for fossil-hybrid operation or can include costeffective storage to meet dispatchability requirements. The systems have low environmental impact and could be beneficial in remote areas as a source of electricity to small communities.

Potential: Siting is restricted to regions with the best solar resources but globally there is significant potential, especially in latitudes +/- 40 degrees latitude. It includes Australia, the Mediterranean region and southwest United States, as there are many appropriate locations in developing countries around the world on all continents.

CSP is currently emerging in many countries of the world; the situation in Spain is one of the most developed. One key to success is to build a sustainable market. In many of the countries, current progress is slow partly due to non-technical barriers. In order to generate a global market, it is important to take the lessons learned in the countries where CSP deployment is successful and transfer them to other countries. This would promote faster market growth, attract larger global companies, and lead to costs that are increasingly competitive with conventional sources. The CSP Global Market Initiative (GMI, www.solarpaces.org/gmi.htm) is a significant reference to be accessed.

The current reality is that:

- Countries that have significant solar resources should consider opening their incentive schemes to CSP technologies.

- Existing resources are not evenly distributed; therefore, it may be logical to consider opening market for the import of solar electricity (e.g., European countries can import from Northern Africa). Higher solar resource levels may more than compensate for additional transport costs while deployment of the technology may help to support political stability in this region.
- Legal frameworks create barriers to optimal use of CSP technologies. Hybrid operation of CSP systems is highly beneficial for both the cost of the solar electricity and for stability of the electrical grid. Legal frameworks should be more flexible to allow this option.
- Incentive schemes do not always span the full range of activities required to achieve RD&D goals. Scaling up CSP to larger power block sizes is an essential step to reduce electricity costs. To ensure that it is possible to fully exploit the cost-reduction potential, incentive schemes should not limit the upper power level.

3.3. Wind Energy

Globally, in the short- to medium-term, wind energy will be exploited predominately in the generation of electricity through on-shore and, increasingly, off-shore installations. In the longer term, there is also high potential for integrating wind and other renewables within the complete energy supply system. Activities will, therefore, also examine the use of wind energy in non-electricity generating applications (e.g., desalination) and within energy systems such as those exploiting hydrogen and other forms of energy storage.

For the mid-term time frame, RD&D areas of major importance for future deployment of wind energy are forecasting techniques, grid integration, public attitudes and visual impact. RD&D to develop forecasting techniques will increase the value of wind energy by allowing electricity production to be forecasted from six to 48 hours in advance. RD&D to facilitate integration of wind generation into the electrical grid – as well as on demand-side management – will be essential when it becomes necessary to transport large quantities of wind-generated electricity through grids. RD&D designed to provide information on public attitudes and the visual impact of wind developments will be necessary to adequately consider such concerns during the deployment process for new locations for wind energy (especially off-shore).

For the long-term time frame, it is vitally important to pursue the RD&D necessary to take large and unconventional steps to make wind turbine and its underlying infrastructure interact in close co-operation. Adding intelligence to the complete wind system, and allowing it to interact with other energy sources, will be essential in areas of large-scale deployment. RD&D to improve electrical storage techniques for different time scales (minutes to months) will increase value at penetration levels by more than 15% to 20%. There is a need to balance efforts for continued long-term research supported by the public sector and internal product development and research carried out within the industry.

Wind energy is expected to continue to show the very strong growth now experienced for many years. Wind energy is a global market place and whilst some well-established markets such as Denmark, Germany, Greece, Sweden and the United States are slowing, others in Europe, Asia, Canada and Australia are stepping in to maintain a very positive picture.

Global growth in 2004 matched that of 2003 at 21.1%, sustaining the very high level seen over the last decade. This is a very strong performance and expectations for the coming years are of continued high growth, which has been sustained at approximately 30% per year since 1994. At the end of 2004, the global wind capacity reached 47.5 GW. Installed wind power for Europe given in Figure 3.8.

Wind technology has become very reliable, operating with availabilities of more than 98% and having a design life of 20 years or more. Moreover, as the costs of wind turbines have steadily declined, technical reliability has increased. The factors that currently limit wind energy’s market penetration include variability, public acceptance and grid reliability. However, recent developments in electricity market reform, which promote better grid integration and improved management of natural cycles of renewables, diminish the technological barriers that have constrained market penetration.

The value of new wind installations worldwide is estimated at USD 7 billion for 2003. This figure is based on an average total project cost of USD 1000/kW installed, excluding operation and maintenance costs.

In the area of wind energy, continued RD&D is essential to provide the necessary reductions in cost and uncertainty to realise the anticipated level of deployment. Other RD&D priorities include increasing the value of forecasting power performance, reducing uncertainties related to engineering integrity, improvement and validation of standards, reducing the cost of storage techniques, enabling large-scale use, and minimising environmental impacts. Further expansion of wind power will promote significant reductions in greenhouse gases. With further deployment support, wind power may become generally competitive with conventional technologies by 2015-20; off-shore wind will likely become competitive to a degree after that.

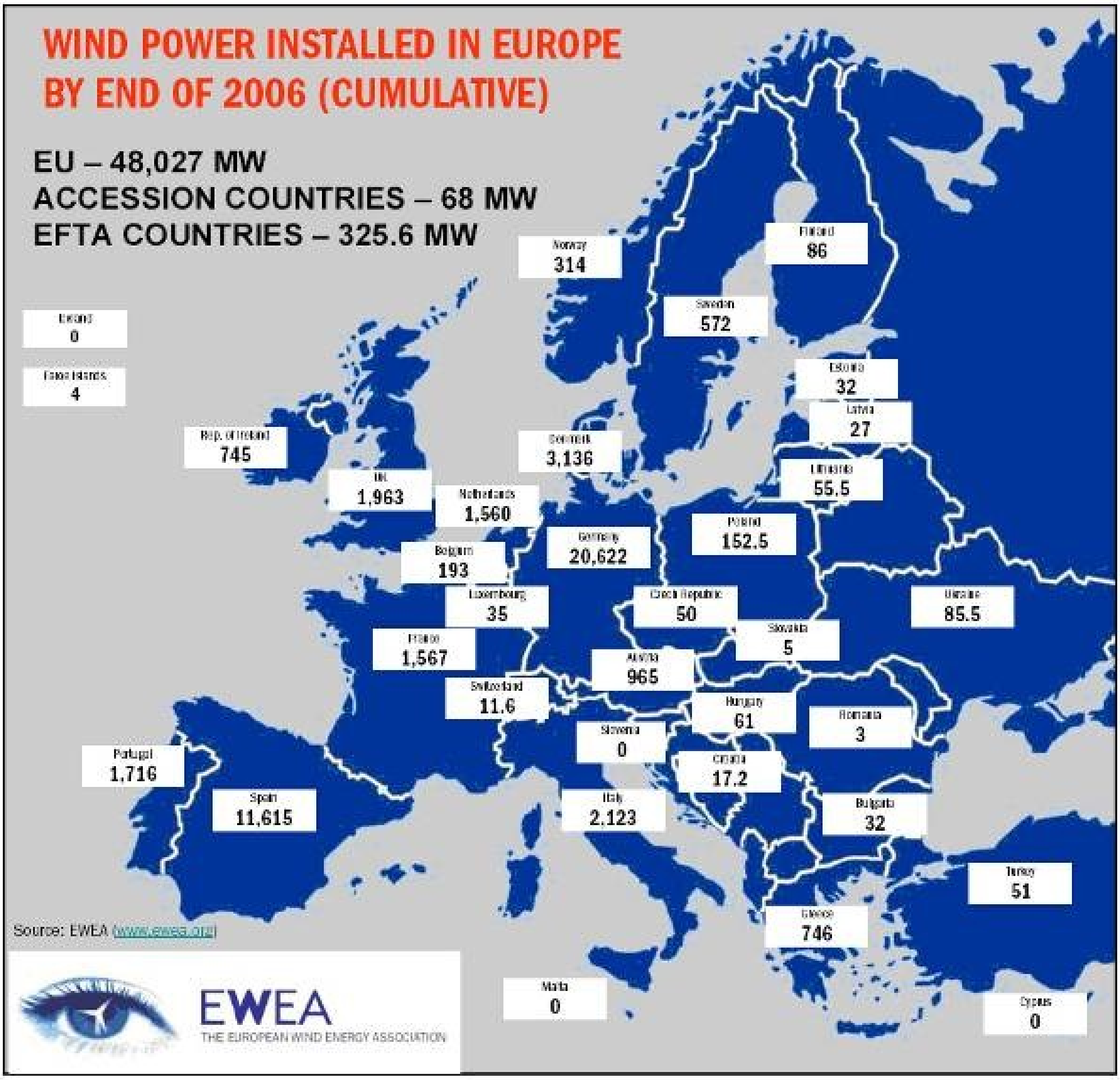


Figure 3.8. Wind power installed in Europe

Current Situation and Applications: Wind energy is considered one of the most promising technologies for electricity generation. Its recent deployment has been one of the fastest growing renewable technologies worldwide. Technical advances over the past two decades, combined with innovative marketing, have expanded capacity from around 2,000 MW in 1990 to 17,300 MW by the end of 2000 8. Europe is the leader with a total of over 12,500 MW by the end of 2000. The United States also has a large capacity, with more than 2,500 MW by the end of 2000. In India installed wind power is over 1,100 MW by 2000, followed by China with 265 MW. Not generally included in the figures are approximately 1 million wind turbines used for water pumping in developing countries as well as tens of thousands used to charge batteries. Wind turbines are seen to be increasingly competitive with conventional generating sources. They can be used as individual turbines or combined in wind farms. They can feed into electricity grids (either from large wind farms or individual producers) or used in stand-alone, off-grid applications. Costs have come down appreciably over the past decade and are now considered commercially viable in many situations.

Wind turbines have proven successful in locations such as islands, northern areas and other remote regions not adequately serviced by grids. They have also proven valuable in providing power for irrigation, watering cattle, cooling and desalination. 9 There is increasing interest in offshore applications, partially due to the stronger wind regimes, and partially to overcome siting limitations on land. The first offshore wind farm was constructed in 1991 in Denmark; a wind farm in deeper water opened in November 2000 in the United Kingdom.

Wind power (new installation capital costs) is projected to expand from $51.4 billion in 2008 to $139.1 billion in 2018. Last year's global wind power installations reached a record 27,000 MW. In the U.S., which accounted for more than 8,000 MW, wind installations represented more than 40 percent of total new electricity generating capacity brought online in 2008 — and moved the U.S. ahead of Germany as the world's leading generator of wind energy.

In the mid-1970s, the oil crisis prompted investigations into energy sources derived from material other than fossil fuels. Wind energy was considered one such energy source that could reduce dependency on fossil fuels. Various designs of wind energy systems were tested and at last, the propeller type, horizontal axis wind turbine was identified as the most promising system for converting the kinetic energy of wind into electricity.

Two kinds of groups began to carry out efforts to develop effective wind turbines. The first one, working within governmental programmes, focused on big, multi-megawatt wind turbines that would be operated by utilities. The second group consisted of activists and entrepreneurs building small turbines, starting at 20 kW. Both groups discovered that designing wind turbines was far more complicated and costly than initially expected.

At the time, the design knowledge base was rudimentary or outdated. The need for RD&D was identified at an early stage and, as a result, many countries initiated national RD&D programmes. Early studies demonstrated that existing knowledge in meteorology, electrical machinery, and aeronautical fields could be applied in wind engineering. Accordingly, wind energy research organisations were, to a large extent, coupled to meteorological and aeronautical research institutes and universities. As time passed and knowledge increased, research topics were directed towards more specific questions relevant to wind technology (e.g., wind modelling, resource assessment, aerodynamics, and structural dynamics). To illustrate the application of the technology, a number of MW-size demonstration programmes were established in the early 1980s. Their main objectives were to improve technology and system integration in order to demonstrate feasibility.

Commercial turbines appeared on the market around 1980, coinciding with the boom in market demand for small turbines (50 kW to 200 kW) in Denmark and California. In spite of the good market conditions, many companies went bankrupt due to technical problems and poor understanding of loads interacting with the wind turbine. The demonstration programmes of MW-class machines in the United States, Germany, Denmark, and Sweden also had problems, mainly related to fatigue. These prototype turbines provided useful information of system behaviour, which was applied in later years.

Later in the 1980s, wind turbines became larger (250 kW to 300 kW). Market demand increased mainly due to subsidies and tax credits. However, an expected lifetime of 20 years was difficult to achieve because of reliability and system integration problems. The technology could not compete economically without support.

In the beginning of the 1990s, wind turbines became larger again and were installed in small groups called wind farms. Increasing national RD&D programmes promoted the trend towards larger turbines with a standard size of around 500 kW. This period’s engineering challenges related to the bigger turbine size and the conditions turbines experienced in wind farms. Problems related to fatigue were reduced through better understanding of the interaction between loads and structures. But the market was turbulent: new companies appeared, smaller companies were purchased, and new collaborations were formed.

Cost of Energy: The cost of wind-generated electricity has fallen steadily over the past two decades, driven largely by technological development, increased production levels, and the use of larger machines. In many areas of the United States, the projected cost of energy for utility-scale production can be as low as USD 0.04/kWh to USD 0.06/kWh, given an excellent resource and MW-plus scale turbines. The cost of energy in Norway, New Zealand, Ireland, Greece and Finland were comparable to United States’ values. Costs are somewhat higher in the UK, Japan and Italy. In Switzerland, the highest costs are reported as USD 0.1/kWh to USD 0.16/kWh. In Switzerland good wind power locations however are situated at altitudes starting at 800 m above sea level in hilly or mountainous country with difficult climatic conditions (ice, cold), turbulent wind, difficult access and landscape protection problems.

For complete wind farms, the estimates of average cost vary according to country, between USD 1 200/kW to USD 1 550/kW of installed capacity. In Japan the highest costs –

up to USD 1 850/kW for small installations – are reported, which reflect additional transport costs resulting from turbine imports from Europe and the United States. Average installation costs may also be higher because of mountainous terrain. In reality, system costs have a range that depends on location, project size and other factors. The cost of the turbine and tower alone can vary between USD 800/kW and USD 1 150/kW, with USD 950/kW being typical. These costs show a split of roughly 75% for the turbine (including tower) and 25% for the balance of plant (foundations, electrical infrastructure, and roads.

For the recent MW-plus machines, the installed costs per unit capacity might not be lower, but overall economics continue to improve. This is because the turbines are on taller towers, which places them in zones of higher wind speeds and, thus, improves energy yields.

Benefits: Wind turbine systems can be stand-alone or for grid-based electricity. Wind turbines come in a variety of sizes that can be as small as a few kilowatts, although the average new turbine is over 500 kW with a growing number exceeding 1 MW. Turbines have recently been getting larger as interest in wind farms increases. However, small turbines for individuals are becoming more popular. They are important in remote regions, including islands and cold climates. Landowners can also make money by leasing land for wind farms.

Using wind turbines for mechanical pumping for irrigation and watering cattle is particularly important in developing countries. Wind turbines have fairly low environmental impact, though noise, visual and siting limitations must be considered.

Potential: Global wind resources are ample and are theoretically capable of supplying a large percentage of energy needs. However, the practical potential is limited by a number of factors, including cost, variability and intermittency, and siting. There have been questions about wind potential, due to variability of output from changing wind speeds. Some researchers feel that these concerns are exaggerated and believe that contributions of up to 1020 per cent and more of total electricity supply are possible without compromising grid reliability 10.

Overall, the wind power market appears likely to continue to be strong. Industry representatives continue to revise their expansion plans upwards. Wind turbines are proving very popular in developing countries such as India, China and Latin America, which is aided through increasing support from IFIs (international financial institutions).

Performance: Cost of energy is the correct economic performance measure for wind turbines. In general, installed turbines perform well with few operational difficulties. On average, commercial plants operate with availabilities of more than 98%. Finland reports lower availabilities, resulting from the turbines operating in extremely cold climates. Capacity factors are typically between 0.20 and 0.35, depending on the wind speed and the turbine used. Spain reported an average capacity factor of 0.21 for 2003, and the United States estimates an average capacity factor of 0.29. Capacity factors for wind turbines installed in Ireland to date generally exceed 0.35, and capacity factors exceeding 0.40 are not uncommon.

Additional RD&D priorities: There is strong support for continued activity in all the areas of wind energy RD&D, with no issues taking precedence over others. However, two topics are key: off-shore wind development and the role of wind energy within hydrogen-based energy supply systems. Offshore wind energy, although in its infancy, is increasingly seen as a vital element of renewables development. Technology and environmental issues raised by off-shore wind energy development are the subject of much research and are likely to form an important part of future activities. In addition to using wind energy for electricity production, the technology could be applied to other energy applications in the longer term - particularly hydrogen generation.

Priority research areas identified include:

- Continue cost reduction.
- Increase value and reduce uncertainties.
- Enable large-scale use.
- Minimise environmental impacts.

3.4. Hydropower

During the first half of the 20th century, hydropower became the world's principal source of electricity. Today it is considered a mature technology and still contributes a significant proportion of the world's renewable energy supply. Thanks to its inherent flexibility, it is now positioned as both a vital component of electrical systems and as the most significant shortto medium-term renewable resource. In 2003, total hydropower supply was 104 Mtoe, accounting for 2.0% of total primary energy supply in IEA member countries. It was also the main renewable energy source, with a share of 37% in total renewable energy supply.

Hydropower continues to face challenges, both in terms of public acceptance and economics. In the latter case, the primary issues are related to the long approvals and construction cycle, high initial costs and, hence, long payback periods.

The maturity of hydropower as a technology, the longevity of existing hydropower plants and of the dams and waterways associated with them, and the high availability and reliability of the power output raises a legitimate question: What RD&D is there left to do or is even necessary? Because many organisations and governments have adopted this attitude, the hydropower improvement business has fallen behind in many areas. It now fails to attract RD&D funding and, in many regions, hiring well-qualified staff is difficult.

Hydropower is an extremely flexible technology from the perspective of power grid operation. Large hydropower provides one of the lowest cost options in today's energy market, primarily because most plants were built many years ago and their facility costs have been fully amortised.

Capital costs for new large plants are about USD 2400/MW, with generating costs in the range of USD 0.03/kWh to USD 0.04/kWh. The technical potential of small hydropower capacity worldwide is estimated at 150 GW to 200 GW. Small hydropower costs are in the range of USD 0.02/kWh to USD 0.06/kWh; the lowest costs occur in good resource areas. Once the high up-front capital costs are written off, plants can provide power at even lower cost levels, as such systems commonly operate without major replacement costs for 50 years or more. At present, only 5% of the global hydropower potential has been exploited through small-scale sites. The principal barriers to exploiting more fully small hydro capacity worldwide are access to transmission systems and environmental and social concerns.

Current Situation and Applications: Hydropower is considered a mature technology. Many projects built in the early decades of the 20th century are still operating today, though most have been rehabilitated, modernized or redeveloped.

The era of large hydropower projects began in the 1930s in North America and has since extended worldwide. Today, most large projects, either under construction or planned, are located in China, India, Turkey, Canada and South America. Potential remains, around the world, to expand both the large number of small hydropower projects and to upgrade existing power plants and dams to produce more energy

Hydropower is the most mature form of renewable energy and accounts for a significant share of electricity generation worldwide. It is primarily used for baseload generation and can be used for peak power production. Hydropower represented approximately 18 per cent of world electricity production in 1997. Most hydropower comes from large hydro dams (greater than 10 MW). In 1997, only around 3.5 per cent of hydroelectricity came from small hydro plants. However, increasing focus on the potential and advantages of small hydropower has led to increasing attention to refine the technology and reduce site costs. Hydropower is mainly used for electricity production. The status of current hydropower technology can be categorised into three areas:

- Large hydropower: The technical challenges for large hydropower are mostly faced by the few manufacturers of large equipment and the numerous suppliers of auxiliary equipment and technology. To meet current technology needs and compete effectively, today's manufacturers and suppliers typically invest in RD&D for their own companies. Over recent years, no major breakthroughs have occurred in machinery; however, the advent of computers led to vast improvements in monitoring, diagnostics, and protection and control technologies, as well as in many other areas.
- Small hydropower: For small hydropower, the technical challenges are a by-product of the large hydropower industry and the application of appropriate technology by small manufacturers, organizations and agencies. Perhaps the greatest difference between the technology status of large and small hydropower is the huge variability of designs, layouts, equipment types and material types used in small hydropower. It can be said that there is no "state of the art" in small hydropower; rather there is a huge body of knowledge and experience in designing and building projects to fit the site and the resources of the developer.
- Additional energy at existing hydropower and dams: One of the greatest opportunities for quick gains to the renewable energy portfolio lies in maximising the energy produced from existing hydropower projects. Gains of 5% to 10% are not an excessive target for most hydropower owners; where there are significant numbers of non-generating dams, the numbers could be much higher. As with any modernisation project, the greatest challenge in this sector may be the risk that expected gains are never realised. This perceived risk, coupled with the challenges of re-licensing, results in an enormous potential being left untapped.

However, the technical challenges associated with understanding the issues and problems of an existing hydropower project can be significant – particularly if few drawings and limited records are available. Here again, the advent of computer technology, monitoring, diagnostics, assessment, modelling and design make it possible to better manage many of the uncertainties.

Ten key issues (Table 3.5.) and a number of broad concerns, for example:

- Ongoing operation and maintenance, particularly in relation to aging equipment.
- Managing forced outages and replacing failed equipment.
- Managing the consequences of risk and related issues such as non-compliance and collateral damages.
- Modernising plant equipment and prioritising investments.
- Preparing for operational changes in new markets.
- Integrating with new generation technology and new generation sources (e.g., wind energy, hydrogen).

Table 3.5. Key issues for hydropower plant owners

1.	**Realise lowest operating costs possible through:**
	• Maintenance management system • Innovative staffing approaches • Training/competency management • O&M decision-making tools • New approaches to maintenance and repair
2.	**Increase plant output capacity and energy through modernisation of:**
	• Hydraulic and mechanical equipment and systems (generation and auxiliaries) • Electrical equipment and system (generation and auxiliaries) • Control, protection, annunciation and surveillance systems • Civil structures (concrete, earth/rock fill and structural steel)
3.	**Increase plant value/revenue through:**
	• Costing and selling ancillary services • On-line discharge measurement systems (hardware and software). • Asset management systems • Improved water management systems
4.	**Reduce losses through:**
	• Improvements in measurements and diagnostics • Hydraulic improvements
5.	**Extend asset life through:**
	• Identification of aging and improved maintenance practices for civil structures • Reliability and risk assessment/asset management • Improvements in surveillance systems and diagnostics
6.	**Implement materials/performance improvements in:**
	• Hydraulic, mechanical and electrical equipment and systems (e.g. transformers, generator stator windings, thrust bearings, turbine runners, gates and valves, etc.) • Civil structures
7.	**Increase public acceptance through:**
	• Positioning hydropower as sustainable • Making financing available for development

Benefits: Hydroelectricity causes no direct emissions; it is easy to quickly adjust the amount of power produced in response to shifts in demand. When power is not needed, large amounts of energy can be stored in high-level reservoirs, in so-called pumped storage. This can supplement intermittent power produced from other renewables, such as wind or solar. Hydropower operates successfully in regulated as well as in de-regulated markets, such as in the Nordic region.

There are some drawbacks because hydro dams can affect water flow, fish spawning patterns and flood considerable areas of land. Initial construction costs of large hydro can be a barrier. These disadvantages have often made large hydro schemes controversial. Electricity production can be affected during periods of drought or reduced precipitation but these factors are often predictable and thus reasonably wellmanaged. Ancillary benefits can include flood controls, irrigation, and recreation.

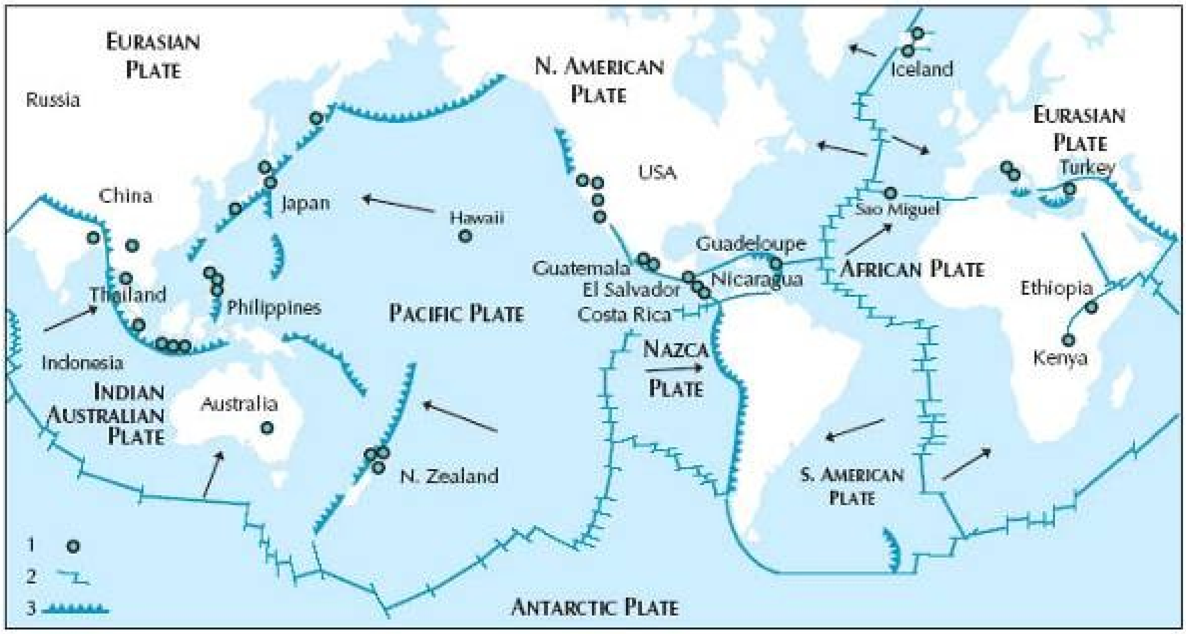
Because of the range of hydro system capacities, they can be sized according to the available resources as well as the needs of the consumer. Small hydro is a simple technique that is easy to maintain and is well suited for distributed or stand-alone production.

Potential: There remains large, untapped potential for expanded large-scale hydropower, particularly in developing countries. In OECD countries, approximately 50-80 per cent of the potential has been achieved. While expansion of large-scale hydro has been hampered due to environmental concerns, there is tremendous interest in small hydro applications. Most future large hydropower projects are expected to be in non-OECD countries.

3.5. Geothermal Power and Heat

Heat energy continuously flows to the Earth’s surface from its interior, where central temperatures of about 6000°C exist. The predominant source of the Earth’s heat is the gradual decay of long-lived radioactive isotopes (40K, 232Th, 235U and 238U). The outward transfer of heat occurs by means of conductive heat flow and convective flows of molten mantle beneath the Earth’s crust. This results in a mean heat flux at the Earth’s surface of approximately 80 kW/km^2. This heat flux, however, is not distributed uniformly over the Earth’s surface; rather, it is concentrated along active tectonic plate boundaries where volcanic activity transports high temperature molten material to the near surface (Figure 3.9.). Although volcanoes erupt small portions of this molten rock that feeds them, the vast majority of it remains at depths of 5 to 20 km, where it is in the form of liquid or solidifying magma bodies that release heat to surrounding rock. Under the right conditions, water can penetrate into these hot rock zones, resulting in the formation of high temperature geothermal systems containing hot water, water and steam, or steam, at depths of 500 m to >3 000 m.

Areas of higher than average heat flow also occur at locations far from plate boundaries (e.g., in France and Eastern Europe). Groundwater circulating deeply along fracture zones in these regions can collect heat from large areas and concentrate it in shallow reservoirs, or discharge it as hot springs. The resulting fluids have lower temperatures than those produced in volcanic systems.



Source: Dickson and Fanelli, 2004.

Figure 3.9. World pattern of plates, oceanic ridges, oceanic trenches, subduction zones, and geothermal fields

Geothermal power plants can operate 24 hours per day, providing base-load capacity. In fact, world potential capacity for geothermal power generation is estimated at 85 GW over the next 30 years. The costs of geothermal energy have dropped substantially from the systems built in the 1970s. Generation costs at current plants in the United States are as low as USD 0.015/kWh to USD 0.025/kWh. New construction can deliver power at USD 0.05/kWh to USD 0.08/kWh, depending on the quality of the resource. However, geothermal power is accessible only in limited areas of the world, the largest being the United States, Central America, Indonesia, East Africa and the Philippines. Challenges to expanding geothermal energy include very long project development times, and the risk and cost of exploratory drilling. Geothermal heat generation can be competitive in many countries producing geothermal electricity, or in other regions where the resource is of a lower temperature.

Enhanced geothermal systems, known as hot dry rock, utilise new techniques to exploit resources that would have been uneconomical in the past. These systems are still in the research phase, and require additional RD&D for new approaches and to improve conventional approaches, as well as to develop smaller modular units that will allow economies of scale on the manufacturing level. Several technical issues need further government-funded research and close collaboration with industry in order to make exploitation of geothermal resources more economically attractive for investors. These are mainly related to exploration of reservoirs, drilling and power generation technology, particularly for the exploitation of low-temperature cycles.

Even in the absence of water, vast amounts of heat are present in rock at accessible depths (< 5 km). This heat constitutes a potential significant worldwide resource. Investigation into its development and utilisation via Enhanced Geothermal System (EGS) projects is currently at the cutting edge of geothermal research.

The very shallowest depths of the Earth (~100 m) can also be used to provide a source for both heating and cooling through the application of geothermal heat pumps, which make direct use of the geothermal energy available virtually anywhere on Earth.

Geothermal resources can differ widely from place to place, depending on the temperature and depth of the resource, the abundance of groundwater and the chemical composition of the rock. Since the technology required to utilise geothermal energy is largely determined by these resource characteristics, technology types and capabilities must also span a wide range.

The general characteristics of geothermal energy that make it of significant importance for both electricity production and direct use include:

- Extensive global distribution; it is accessible to both developed and developing countries.
- Environmentally friendly nature; it has low emission of sulphur, CO2 and other greenhouse gases.
- Indigenous nature; it is independent of external supply and demand effects and fluctuations in exchange rates.
- Independence of weather and season.
- Contribution to the development of diversified power sources.

Geothermal energy can be used very effectively in both on- and off-grid developments, and is especially useful in rural electrification schemes (e.g., Indonesia and New Guinea). Its use spans a large range from power generation to direct heat uses, the latter possible using both low temperature resources and "cascade" methods. Cascade methods utilise the hot water remaining from higher temperature applications (e.g., electricity generation) in successively lower temperature processes, which may include binary systems to generate further power and direct heat uses (bathing and swimming; space heating, including district heating; greenhouse and open ground heating; industrial process heat; aquaculture pond and raceway heating; agricultural drying; etc.)

Current Situation and Applications: Geothermal energy, in the form of hot pools and springs, has been used for bathing, balneology, heating and washing purposes in many parts of the world for thousands of years. Electricity was first generated using geothermal energy in 1904, at Larderello (Italy), and it was there that the first commercial generation began in 1913. Geothermal energy has been utilised on a large scale for both direct use and electricity generation for more than 45 years. At present, geothermal resources have been identified in more than 80 countries, with recorded geothermal utilisation in 71 countries. In 2003, total geothermal energy supply was 20 Mtoe, accounting for 0.4% of total primary energy supply in IEA member countries and 7.1% of total renewable energy supply.

Geothermal is used for power generation 19 or space heating. Electricity generation by geothermal is a baseload technology, and can be a low-cost option if the hot water or steam resource is at high temperature and near the earth's surface. With more than 70 years of commercial application, the technology is well established and commercially viable. The use of geothermal is expanding, growing between 1975 and 1995 by around 9 per cent per year (for electricity production) and 6 per cent per year (for direct use).

Over 46 countries are currently exploiting geothermal power and heat resources. The largest capacity gains through the 1990s were in the Philippines and Indonesia but they still trail the United States in total installed capacity. The use of heat pumps is becoming more popular in countries such as the United States.

In 2004, 24 countries used geothermal energy to generate electricity, with a total installed capacity of 8 902 MWe, generating 56.8 TWh. This is about 0.3% of the 2003 global electricity production. For comparison purposes, it was estimated that the worldwide geothermal potential for electricity generation at about 2 000 TWh/a for currently identified resources, and about 11 000 TWh/a for both identified and unidentified resources. This implies that there are sufficient geothermal resources available for electricity generation well into the future.

The history of worldwide installed geothermal capacities from 1975-2005 and electricity generation for 1995-2005 shows interesting trends. After a rapid rise during 1975-80, average growth in installed capacity levelled off and has remained linear at about 200 MWe/year for the past 25 years. During the periods 1995-2000 and 2000-05, installed capacities increased by 17.3% and 11.6%, respectively, while corresponding increases in electricity generated were markedly higher at 30.5% and 15.4%, respectively.

The number of countries utilising geothermal energy to generate electricity has more than doubled in the past 30 years, increasing from 10 in 1975 to 24 in 2004. In several countries, installed geothermal capacity and energy generated make very significant national contributions (capacity, generation); in others, installed capacities have increased significantly in the past five years. In addition, three new countries - Austria, Germany and Papua New Guinea - recently began generating geothermal power for the first time.

Many of the world's developing nations are located along active tectonic plate boundaries, and hence have good prospects for geothermal resources. Some have already identified significant geothermal resources; others have begun installing or are already operating major geothermal developments. Consequently, geothermal is well placed to make important contributions to the development of these countries.

The capacity factors for geothermal electricity generation range from approximately 40% to 95%, with an average of about 70% for 21 countries in 1999. In many cases, when geothermal power stations operate as base load, their capacity factors exceed 95%.

Benefits: Emissions can result from geothermal production, including carbon dioxide and hydrogen sulphide, but they are considered to be much lower than emissions from fossil fuels. Brines can be produced in sedimentary basins, which are re-injected into the reservoir.

Potential: There are identified geothermal resources in more than 80 countries and the accessible resource base is estimated at 600,000 EJ. The useful accessible resource base for electricity production is estimated at 12,000 TWh/year 21. Only a small fraction of that has been exploited.

Cost of geothermal electricity: Geothermal power plants can range in size from very small (100 kW) to very large (100 MW), depending on the resource and the need. Geothermal technology is suitable for national grid, as well as rural electrification and mini-grid applications. As suggested above, geothermal energy can make significant contributions to the energy needs of developing countries.

The costs of geothermal power depend largely on the character of the geothermal resource and the size of the project, and range from USD 0.025/kWh to more than USD 0.10/kWh (Table 3.6.). Major factors influencing costs are: the resource depth and temperature; well productivity; environmental compliance; economic factors (e.g., scale of development and financing cost); and project infrastructure.

Direct capital costs for geothermal power developments also vary widely (Table 3.7.), ranging from USD 1 150/kW installed capacity for a large plant utilising a high quality resource to USD 3 700/kW installed capacity for a small plant on a low quality resource. Indirect costs - which depend upon the site location and its accessibility, as well as the level of infrastructure and foreign expertise required - range from 5% to 10% of direct costs in a developed country to 10% to 30% in a remote area of a developed country. In a remote area of a developing country, they can rise as high as 30% to 60% of direct costs. Indicative operations and maintenance (O&M) costs for geothermal developments also vary according to the size of the project, ranging from USD 0.008/kWh to USD 0.014/kWh for small plants, from USD 0.006/kWh to USD 0.008/kWh for medium plants, and from USD 0.004/kWh to USD 0.007/kWh for large plants.

Table 3.6. Cost of geothermal electricity as a function of resource quality and plant size

	Unit Cost (USD/kWh)* Medium		
Plant Size (MW)	**High Quality Resource (T> 250 °C)**	**Quality Resource (T = 150-250 °C)**	**Low Quality Resource (T < 150 °C)**
Small (< 5)	0.05-0.07	0.055-0.085	0.06-0.105
Medium (5-30)	0.04-0.06	0.045-0.07	NNS
Large (> 30)	0.025-0.05	0.04-0.06	NNS

Source: The World Bank, 2000.

** These are costs for single flash separation developments in year 2000 USD assuming a capacity factor of 90% .*

NNS = normally not suitable.

Table 3.7. Direct capital costs for geothermal developments

Direct Capital Costs (USD/kW Installed Capacity)*

Plant Size (MW)	High Quality Resource (T> 250 °C)	Medium Quality Resource (T = 150-250 °C)	Low Quality Resource (T < 150 °C)
Small (< 5)	1 600-2 300	1 800-3 000	2 000-3 700
Medium (5-30)	1 300-2 100	1 600-2 500	NNS
Large (> 30)	1 150-1 750	1 350-2 200	NNS

Source: The World Bank, 2000.

** These are costs for single flash separation developments in year 2000 USD*

NNS = normally not suitable.

Total costs for geothermal development for electricity production can be subdivided into several categories:

- Environmental impact assessments for proposed development

USD 100 000 to USD 1.0 million.

- Reconnaissance

Up to USD 100 000.

- Exploration programme

Up to several million USD.

- Well drilling (exploration and production)

Several million USD per well, with about 60% success rate for exploration wells. Thus, drilling costs are typically 30% to 50% of the total development costs.

The lowest power plant costs are for the rare steam fields (e.g., Larderello and Geysers), where steam from the well is piped directly to the turbine. For the more common high temperature, liquid-dominated systems (i.e., the reservoir fluid is hot water or steam/water mixture), either a single or double flash system is used to separate the steam, which is piped to the turbine. The remaining separated hot water is available for further electricity generation (via a binary plant) and direct use (heat) applications. Binary cycle systems, which use heat from the geothermal fluid to vaporise a secondary fluid that drives a turbine, can operate using lower temperature fluids and are more economic for the lower temperature systems (T <175 °C). Flash system power plant costs are generally higher than those for the steam fields. Although binary systems are generally the most expensive, recent analyses indicate that they are becoming competitive with flash systems, with capital costs of approximately USD 1 800/kW.

The unit cost of geothermal power decreases rapidly with increasing plant capacity factor, i.e., maximum return is obtained from maximum operation. An increase in plant capacity factor from 50% to 90% would be expected to reduce the cost of producing electricity by almost 50%.

Cascaded use of geothermal fluid at successively lower temperatures allows multiple applications of the original fluid, thereby increasing thermal utilisation efficiency and reducing overall production costs. For example, the separated hot water from a high temperature geothermal power development can be used in a binary cycle plant to produce more electricity at lower temperatures. The water from the binary cycle plant may be used at still lower temperatures in the production of silica and other marketable products (zinc, arsenic, manganese, lithium, etc.) or for direct heat uses (agriculture, aquaculture, district heating, bathing, etc.).

A recent review of the public sector information available on geothermal power development for the period 1986-2000 provides interesting insight. Figure 22 indicates that capital costs for double flash systems decreased from about USD 3 500/kW in 1988 to about USD 1 800/kW in 2000 (a drop of 49%). Costs for single flash declined from USD 2 500/kW in 1987 to USD 1 500/kW in 2000 (40%). Binary plant costs show the most significant decrease, declining from approximately USD 5 100/kW in 1986 to USD 2 400/kW in 2000 (55%). Consequently, overall costs in geothermal power production fell by almost 50% from the mid-1980s to 2000. As mentioned above, current binary costs can be as low as USD 1 800/kW (a 65% decrease since 1986), making this technology competitive with flash systems.

Clearly, significant cost reductions – as high as 50% – have been realised for both flash and binary technologies over the past 20 years. Binary costs show a continuous decline; flash costs decreased until about 1996-97, then appear to level out - and even increase slightly - in the later 1990s.

Such large cost reductions often result from solving the “easier” problems associated with the early years of science and technology development. Future cost reductions may come in smaller steps and be more difficult to attain.

Geothermal energy for electricity and direct heat applications is a mature technology with a long history in many countries. Some estimates project the potential for a substantial growth rate in geothermal electricity production in the next couple of decades. Much of development could be from known suitable resources, particularly in the developing countries of Southeast Asia, Latin America and Africa, where many of the untapped resources are found and demand is growing rapidly. In addition, significant opportunities exist for continued rapid growth in direct heat use, which already experienced a doubling in utilisation between 1995 (112 441 TJ/year) and 2000 (190 699 TJ/year), and again between 2000-05 (261 418 TJ/year) Geothermal heat pumps contributed greatly to the latter increase (amounting to 33% of the 2005 total direct heat use) and demonstrated that geothermal energy can be utilised almost anywhere in the world, for both heating and cooling (See Table 3.8.).

For geothermal, as with other more technically mature technologies, to achieve the desired and possible accelerated growth, the priority is to become more cost-effective in the market place. In this case, the obstacles include cost and the market's perception of cost. These result partly from the failure of the market place to fully account for the external cost of competing conventional technologies. Another barrier lies in the difficulty of characterising the geothermal resource prior to making a major financial commitment. Other impediments to market penetration arise from a general lack of public awareness and experience with the technologies, and from social and environmental barriers linked to lack of experience with planning, regulation, and gaining public acceptance. As with other renewable energy sources, energy from geothermal resources has significant positive environmental benefits at the global level. However, deployment can have a local impact (mainly for limited-time operations such as drilling), so projects do not always enjoy universal local support.

Additional RD&D priorities: In the case of geothermal energy, several topics are identified as being key to its advancement in the global market place. These are related to cost reduction, sustainable use, expansion of use into new geographical regions, and new applications. The priorities are categorised as “general” or specific to RD&D.

General priorities:

- Life-cycle analysis of geothermal power generation and direct use systems.
- Sustainable production from geothermal resources.
- Power generation through improved conversion efficiency cycles.
- Use of shallow geothermal resources for small-scale individual users.
- Studies of induced seismicity related to geothermal power generation (conventional systems and **E**nhanced **G**eothermal **S**ystems (EGS).

Table 3.8. Geothermal direct heat applications

Direct use category	**Capacity (MWt)**				**Utilization (TW/y)**			**Capacity Factor**	
	2005	**2000**	**1995**	**2005**	**2000**	**1995**	**2005**	**2000**	**1995**
Geothermal Heat Pumps	15 723	5 275	1 854	86 673	23 275	14 617	0.17	0.14	0.25
Space Heating	4 158	3 263	2 579	52 868	42 926	38 230	0.40	0.42	0.47
Greenhouse Heating	1 348	1 246	1 085	19 607	17 864	15 742	0.46	0.45	0.46
Aquaculture Pond Heating	616	605	1 097	10 969	11733	13 493	0.56	0.61	0.39
Agricultural Drying	157	74	67	2 013	1 038	1 124	0.41	0.44	0.53
Industrial Uses	489	474	544	11 068	10 220	10 120	0.72	0.68	0.59
Bathing and Swimming	4 911	3 957	1 085	75 289	79 546	15 742	0.49	0.64	0.46
Cooling/Snow Melting	338	114	115	1 885	1 063	1 124	0.18	0.30	0.31
Others	86	137	238	1 045	3 034	2 249	0.39	0.70	0.30
Total	**27 825**	**15 145**	**8 664**	**261 418**	**190 699**	**112 441**	**0.30**	**0.40**	**0.41**

3.6. Bioenergy

Bioenergy has several unique characteristics that distinguish it from the other **R**enewable **E**nergy **S**ources (RES) that, individually, can be considered as either advantages or disadvantages. But on the whole, biomass offers good potential as an important RES of the future. Biomass is defined as any plant matter used directly as fuel or converted into other forms before combustion. Included are wood, vegetal waste (including wood waste and crops used for energy production), animal materials/wastes, sulphite lyes, also known as "black liquor" (an alkaline-spent liquor from the digesters in sulphate production or soda pulp during the manufacture of paper where the energy content derives from the lignin removed from the wood pulp) and other solid biomass.

Biomass in the form of biofuels (solid, liquid or gaseous) is the only RES that can directly replace fossil fuels (solid, liquid and gaseous), either fully or in blends of various percentages. In the latter case, the replacement can often be implemented without requiring any equipment modifications.

In the case of co-utilisation with fossil fuels and subsequent carbon sequestration, bioenergy offers the only option to actually withdraw carbon from the environment. Biomass also has the advantage, in comparison to other RES, that it can be stored over long periods of time. On the other hand, in comparison to fossil fuels, it has the disadvantage of a relatively low energy density (energy content per unit volume or unit mass), leading to high transport cost.

Biomass is the only renewable energy source that is not freely available; producing it requires a long chain of activities such as planting, growing, harvesting, pre-treatment (storage and drying), upgrading to a fuel, and finally mechanical, thermochemical or biological conversion to an energy carrier (power, heat or biofuels for transport). Thus, biofuels (with the exception of untreated municipal waste) always have associated costs that must be carried by the end-user.

In contrast to the local nature of all other renewable energy sources, biomass and biofuels are traded on local, national and international markets. Although international trade in biomass fuels (solid or liquid) is still in its infancy, it is expected to play a major role in the development of a limited bio-economy.

By its very nature, bioenergy cuts across several policy areas in addition to energy policy including: agricultural and forestry, environment, employment, trade and market, tax policies, regional development, et al.

Due to the limited availability of land, one can foresee a future in which biomass for energy must be balanced against the need for food, materials, biochemicals and carbon sinks. However, this point in time is beyond 2020 and, if international trade in biomass fuels becomes effective, this date could well be postponed beyond 2050.

Environmental concerns associated with biomass production (for food, products or fuels) still need to be addressed. This must be done with an overall systems approach—rather than in an isolationist manner—allowing for comparisons to other alternatives.

Biomass combustion for heat and power is a fully mature technology. It offers both an economic fuel option and a ready disposal mechanism of municipal, agricultural and industrial organic wastes. However, the industry has remained relatively stagnant over the last decade, even though demand for biomass (mostly wood) continues to grow in many developing countries. One of the problems of biomass is that material directly combusted in cook stoves produces pollutants, leading to severe health and environmental consequences; although improved cook stove programmes are alleviating some of these effects. A second issue is that burning biomass emits CO2, even though biomass combustion is generally considered to be "carbon-neutral" because carbon is absorbed by plant material during its growth, thus creating a carbon cycle. First-generation biomass technologies can be economically competitive, but may still require deployment support to overcome public acceptance and small-scale issues.

About 14 million hectares of land are currently used for the production of biofuels – about 1% of the world's available arable land. This share rises to 3.5% in the Alternative Policy Scenario. Rising food demand, which will compete with biofuels for existing arable and pasture land, will constrain the potential for biofuels output, but this may be at least partially offset by higher agricultural yields.

More modern forms of bioenergy include biomass-based power and heat generation, co-firing, biofuels for transport and short rotation crops for energy feedstocks. These are more advanced and each has its own unique benefits. Biomass is attractive for use either as a stand-alone fuel or in fuel blends, such as co-firing wood with coal, or mixing ethanol or biodiesel with conventional petroleum-based fuels. Anaerobic digestion has strong potential in countries with ample resources. Electricity generated from biomass is based on steam turbine technology. Many regions of the world still have large untapped supplies of biomass residues, which could be converted into competitively priced electricity using steam turbine power plants. Co-firing is a low-cost and low-risk way of adding biomass capacity. Co-firing systems that use low-cost biomass supply can have payback periods as short as two years. In addition, biomass can substitute up to 15% of the total energy input in a power plant, often with few modifications other than the burner and feed intake systems. Co-firing is of particular interest in developing countries, because it improves the economic and ecological quality of many older, coal-fired power plants.

Biofuels from agricultural biomass production is another well-developed conversion technology. Biomass grown as dedicated energy crops can provide new economic opportunities for farmers and forest owners. The primary barriers to increased use of biomass on a larger scale are the cost of systems required for dedicated feedstock production, harvesting, and transportation, as well as the fuel conversion technologies. With further RD&D and deployment support in 2020-30, these technologies could achieve commercialisation.

Current Situation and Applications: Bioenergy resources are widely available worldwide and have the largest share of all renewable energy sources. Biomass resources come in many forms. Traditionally, wood, crop residues and animal waste have been used for heating or cooking, but today biomass is also used in many other ways. **M**unicipal **S**olid **W**aste (MSW) can be used for heat or electricity. Landfill gases can be used for heat, electricity or fuels. Biological conversion of MSW using anaerobic digestion can produce electricity, heat or fuel gas. Wood and wood wastes can be used to produce electricity, heat for industrial purposes or domestic space heating.

Biofuels (global production and wholesale pricing of ethanol and biodiesel) reached $34.8 billion in 2008 and are projected to grow to $105.4 billion by 2018. In 2008 the global biofuels market consisted of more than 17 billion gallons of ethanol and 2.5 billion gallons of biodiesel production worldwide. For the first time, ethanol leader Brazil got more than 50 percent of its total national automobile transportation fuels from bioethanol, eclipsing petroleum use for the first time in any major market.

Benefits: There is a wide variety of feedstock available. Much of that feedstock, e.g. municipal solid waste, solves disposal problems faced by local authorities. Energy crops can bring major benefits to farming communities to supplement their income. In many developing countries, improved combustion efficiency can bring many benefits relating to the pressure on woodlands (e.g. reduced resource base) and the problem of desertification.

Biofuels have important environmental benefits because they reduce exhaust emissions and their biodegradability means that fuel spills can be much less damaging.

Potential: The potential has been estimated to be in the range of 200-300 EJ/a (Exajoules per annum), up from the current 50 EJ/a. The potential is high due to the extent of the resource base in all countries, which can be expanded through bioenergy crops. There is a great potential for using municipal waste, because anaerobic digestion of wastes provides a strong alternative to landfill and yet deals effectively with much of the local waste concerns.

Current technology status: Generating bioenergy involves complex conversion processes that can follow many possible pathways from raw material to finished product, as well as a range of competing applications for various biofuels (Figure 3.10.). A matrix of competing pathways further demonstrates the complexity of the sector (Figure 3.11.). However, these diagrams also demonstrate the innovation capacity of the bioenergy research community and related industry: they have made it possible to use almost any type of biomass for multiple conversion technologies (after pretreatment and upgrading to a fuel quality).

Over the past decade, bioenergy technologies achieved significant cost reductions in several important areas including: dedicated large- and small-scale combustion; co-firing with coal, combustion of municipal solid waste; biogas generation via anaerobic digestion; and in district and individual household heating. In certain geographical areas, cost reductions were also realised in liquid biofuels such as bioethanol and biodiesel.

However, operating costs still differ significantly from country to country due to wide variations in the cost of the biomass fuel delivered to the gate of the conversion plant. Such variations are due to two factors: a) the actual cost of the raw biomass; and b) local policies related to agriculture and forestry including: taxes; labour costs for the cultivation, production and harvesting of the resource; and labour costs for the operation of the conversion facilities. This variability makes it impossible to generalise the production costs of biomass or biomass fuels delivered to the conversion plant or, indeed, the production cost of energy generated from biomass sources.

Some of the pathways shown in Figure 3.10., such as pyrolysis and the synthesis gas route for liquid biofuels, are still in the development phase and may require five to ten years further work before they can be considered as commercial technologies. In an ideal scenario, all bioenergy applications should aim for polygeneration, i.e., the simultaneous production of heat, cooling, power and fuels, and – whenever possible – chemicals and materials. Such conditions are a prerequisite for maximising overall conversion efficiency and generating the greatest possible benefit per unit mass or unit volume of biomass.

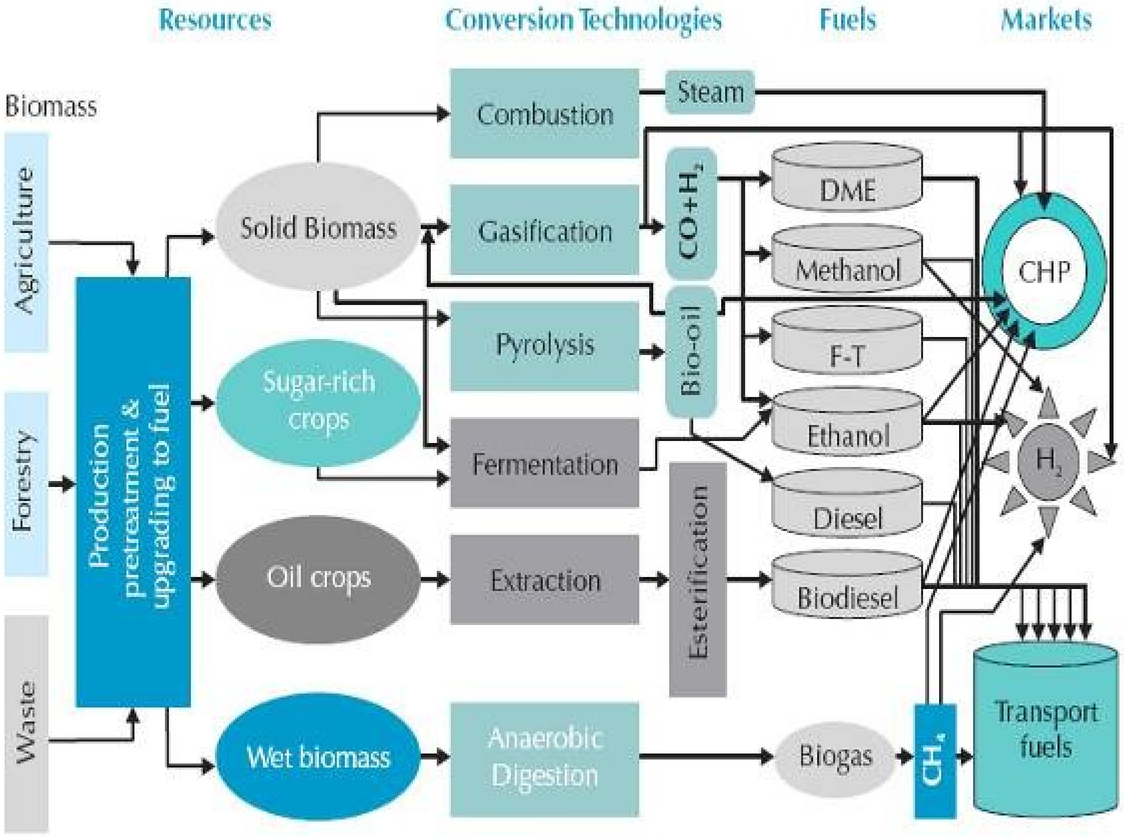


Figure 3.10. Biomass conversion pathways to energy and fuels

In practice, it is difficult to identify precise circumstances in which polygeneration can be applied under existing economic conditions. However, industry shows a clear tendency to advance beyond simple power generation to achieve polygeneration.

Costs for bioethanol can vary from USD 0.20 to USD 0.81 (a four-fold difference) subject to the location and the crop/resource used to produce the biofuel. Similarly, the cost for producing biodiesel can vary from USD 0.40 to USD 0.80 (a two-fold difference). There is good potential to further decrease production costs of both biofuels, especially in Europe and the United States, through innovative combinations of technologies and improved utilization of process residues. It may also be possible to use municipal wastes as a feedstock.

Gasification technologies are still in the development stage and very few reference operating plants exist, thus making it difficult to generalise about production costs. However, due to its flexibility in terms of final use of the fuel gas produced, gasification may offer significant opportunities once the sector is able to overcome remaining technical barriers, demonstrate reliability and further reduce costs.

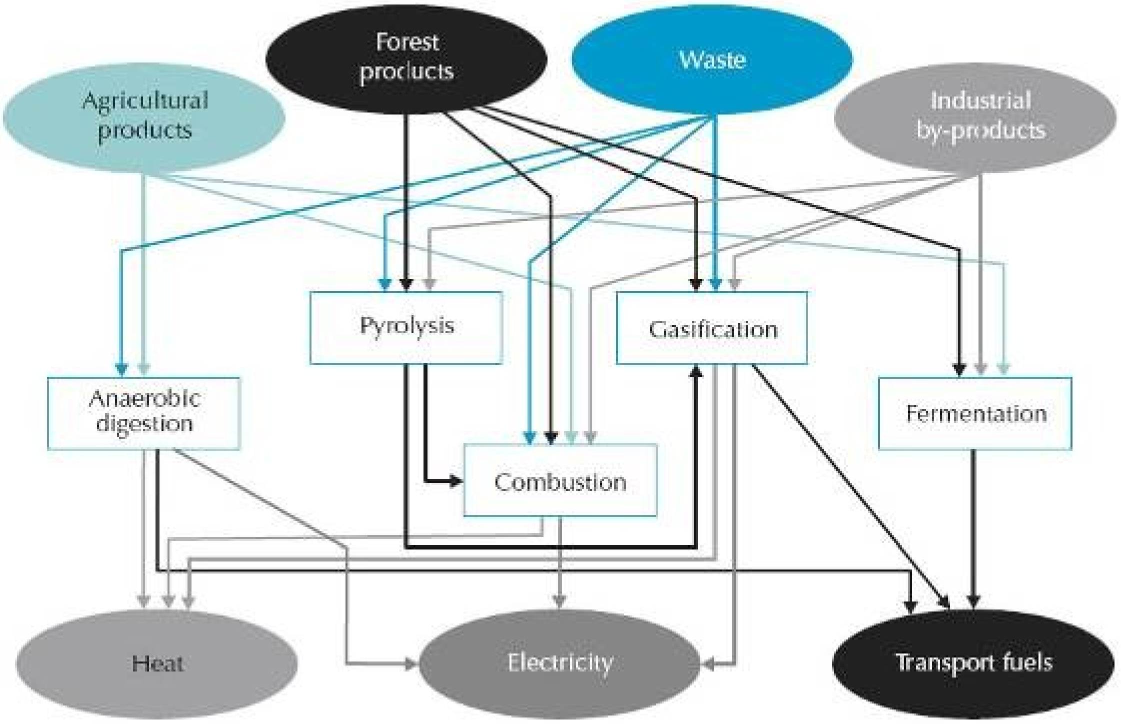


Figure 3.11. Simplified bioenergy matrix

In general, at a small scale, gasification promises higher efficiencies. However, at a larger scale, improvements in combustion are now also achieving higher efficiencies. The advantages of gasification systems arise from high efficiency in converting biomass to a gas and in utilising heat from combustion of the gas produced. This includes larger scale power generation of up to 100 MWe with Integrated Gasification Combined Cycle (IGCC) processes, which demonstrate predicted electricity production efficiencies of 40% to 50% compared with only 25% to 35% via traditional combustion. Small-scale power generation systems (up to 5 MWe) use engines that offer up to 35% efficiency. So far, neither of these thermochemical conversion processes has been able to penetrate markets to any significant extent. This is primarily due to high costs and a perception that the technologies must still be proven at large scales.

The key differences between thermal and biological conversion lie in the time involved, the end products and the resulting residues. Biological conversion is a slow process – typically taking hours, days, weeks (anaerobic fermentation) or years (landfill gas by digestion) to complete reactions - and delivers single or specific products such as ethanol or biogas (which contains up to 60% methane). Thermal conversion is characterised by very short reaction times (typically seconds or minutes) and its ability to deliver multiple and complex products. Often, thermal conversion uses catalysts to improve the product quality or spectrum. Biological conversion effectively converts only a fraction (about 50% to 60%) of the total feedstock (e.g., sugars or cellulose), resulting in large residual streams that can be used for other commercial purposes (e.g., compost or animal fodder). In contrast, thermal treatment converts the entire feedstock, leaving only ashes (about 2% to 4% weight). To date, few studies exist concerning the status of various biomass conversion technologies (Bridgewater and Maniatis, 2004). However, it is interesting to compare a tentative status for biomass conversion technologies in view of their market attractiveness for generating power, heat or liquid biofuels and in relation to the current strength of various conversion technologies.

Anaerobic digestion is a successful technology for the production of biogas and is now used commercially all over the world - especially for waste effluents such as waste water, sewage sludge, and abattoir waste streams, as well as for the biological portion of municipal solid waste. While liquid state technologies are currently the most common, recently developed solid state fermentation technologies are also widely used, especially for substrates with moisture content in the range of 30% to 40% wt. Technically, anaerobic digestion technologies are very reliable. However, they are site specific and their scaling up capacity is limited; thus their market attractiveness is somewhat restricted. That said, it should be noted that the increasing costs of waste disposal are improving the economic attractiveness of anaerobic digestion processes.

Co-firing applications are perhaps the most interesting in terms of their potential for accelerated market penetration: thanks to the existence of the power cycle in coal-fired power plants, overall costs are relatively low. In addition, cofiring has the advantage over co-combustion (in which biomass fuels are mixed with coal before or during the combustion process) in that the biomass residual ash is not mixed with the coal ash, which has an existing market as a construction material. Moreover, the technical risks of co-firing are low: because hot gas is used, there is no tar problem. Reburning applications (in which the fuel gas is introduced near the top of the coal boiler) show significant improvements in the environmental performance of the power station and in the replacement of fossil fuels by renewable biomass fuels.

Combined Heat and Power (CHP) applications are attractive for several reasons: overall efficiency is increased substantially, the technology is reliable and the need to identify a heat client is manageable. However, the combination of both the heat and power energy vectors makes CHP applications more site specific than when using each energy vector separately. In order to reduce operational costs, it is often necessary to implement multi-fuel operation, which increases the complexity of the feeding system and the flue gas cleaning. This results in some degree of increased maintenance. Recently, more attention is directed towards polygeneration systems that can produce power, heat and cooling, thereby maximizing overall efficiency.

While downdraft gasifiers and fluidised bed systems are beginning to show a degree of success, gasification technologies to power still need to demonstrate reliable commercial operation. The main barriers are efficient tar removal (technical) and economics (non-technical). The success of the Värnamo plant in Sweden - the first and only plant to demonstrate an Integrated Gasification Combined Cycle (IGCC) based on biomass - and recent advances on tar elimination indicate that these problems could be overcome in the short to medium future.

Flash pyrolysis for the production of bio-oil is another attractive process in that the bio-oil can be stored and transported, thereby separating the conversion and energy production processes. At present, no large-scale demonstration plants are able to provide reliability for commercial energy applications, although Dynamotive recently established a production facility in West Lorne, Canada.

Production of bioethanol and biodiesel, from sugar and oil-based crops respectively, are well-established industrial processes. Their overall energy and carbon dioxide balance - although positive - could be improved significantly through on-site utilisation of the plant residues for CHP applications, as practised in Brazil with sugarcane and bagasse. The technical reliability of these traditional technologies is very high but their market attractiveness is limited in view of carbon emissions trading. New applications, such as biodiesel from used cooking oils and animal tallow, are coming on stream together with pilot facilities to produce ethanol from lignocellulosics. Again, it is necessary to prove the technical reliability of these applications but if these technologies can be commercialised, their market attractiveness will increase significantly. Production of biofuels for transport applications must also carefully consider fuel quality specifications to ensure operation ability of car fleets already on the market, which requires cooperation of the oil and automotive industries.

Biohydrogen is another potential alternative that can be produced from biomass in a variety of ways, the most straightforward being the reforming of biomethane produced from biogas and the reforming of bioethanol (it can also be created from synthesis gas via gasification). However, these technical approaches are at the very early research stage and relatively far from market applications.

3.7. Ocean Energy Systems

The oceans contain a huge amount of power that can be drawn from different sources and exploited for generating useful energy. Compared to other renewable energies, technologies to extract energy from this resource are in an early stage of development. Investment in ocean energy RD&D captured a small fraction of the total renewable RD&D budgets in IEA member countries over the past 30 years. However, the resource is theoretically much greater than world energy demand.

The most developed conversion systems concern tidal energy, thermal energy, marine currents and ocean waves. Tidal energy results from the gravitational fields of the moon and the sun. Winds blowing over the ocean surface generate ocean waves. Thermal energy (ocean thermal energy conversion or OTEC) derives directly from solar radiation, drawing energy from the thermal gradient of temperature differences between surface water and cold deep water. Marine currents are caused by thermal and salinity differences, as well as by tidal effects. Salinity gradient utilises the pressure difference arising between fresh water and sea water. All of these characteristics of the marine environment represent untapped power sources. Other technologies, namely salinity gradient devices, also show potential but are at a much lower level of development.

IEA governments allocated about USD 0.8 billion (2004 prices and exchange rates) for RD&D on ocean energy from 1974-2003. The United States accounted for about 53% of reported governmental RD&D funding. In the near term, ocean energy technologies will continue focus on executing prototype deployments and on investigating multi-device, large-scale deployments. In the medium term, these technologies may become significant contributors to those markets adjacent to the resource. In the longer term, when hydrocarbon scarcity becomes a more serious constraint and new forms of energy transmission are required, ocean energy could become a much more important part of the world’s energy portfolio.

Over the last 20 years, ocean energy technology received relatively little RD&D funding. However, there is renewed interest in the technology, and several concepts now envisage full-scale demonstration prototypes around the British coast. But ocean energy technologies must still solve two major problems concurrently: proving the energy conversion potential and overcoming a very high technical risk from a harsh environment. Other non-technical barriers include resource assessment, energy production forecasting and design tools, test and measurement standards, environmental impacts, arrays of farms of ocean energy systems, and dual-purpose plants that combine energy and other structures.

3.8. Wave Energy Systems

Wave energy systems are divided into two main categories, fixed devices and floating devices. A fixed device has a solid foundation. This foundation can be incorporated either in the coastline, in a breakwater structure, or on an off-shore platform that is fixed on the seafloor.

Today's most advanced concepts are installed on the shoreline. A floating device is a completely floating structure, like a ship, that can be linked to the shore via a high voltage power cable. Such devices are kept in position with either mooring systems or motors. Within each group there is a range of wave energy technologies under development. Because their specificities are so wide ranging, defining all RD&D needs would lead to a large list of small details important for individual concepts. The focus here is on common concerns and needs including: wave behaviour and hydrodynamics of wave absorption; structure and hull design method; mooring; power take-off systems; and deployment methods.

Current Situation and Applications: Oceans provide a number of recoverable energy sources through technologies such as tidal barrage, wave energy, tidal/marine currents, **O**cean **T**hermal **E**nergy **C**onversion (OTEC), salinity gradient/osmotic energy and marine biomass. Three tidal barrages currently operate as commercial power plants, amounting to a worldwide total of 260 MWe of installed capacity. In addition, two wave power installations – also commercially run – accumulate around 750 kWe of peak power. As yet, tidal current systems, OTEC installations and salinity gradient concepts have been tested only as prototypes. A great deal of research and technological development needs to be done to bring ocean energy technologies to maturity. Ocean energy systems confront the marine environment in its most energetic location, implying a need for devices that can withstand strong wave climate and/or strong currents while also fulfilling basic economic and environmental requirements such as low cost, safety, reliability, simplicity and low environmental impact.

Tidal barrage technology is not considered in this text for two reasons. Firstly, the concept is based on mature hydropower components requiring limited research development to adapt to the marine environment. Secondly, their environmental impact on local ecosystems prevents widespread deployment. However, an in-depth analysis of the three existing installations would provide crucial information to help policy makers assess proposals when developers come forward with new project ideas.

Of the ocean technologies, tidal energy is considered the most predictable because its variation over the tidal cycles can be predicted with considerable accuracy. Wave power depends on the weather and so is more intermittent. Ocean currents are relatively constant, but have not been fully mapped for their commercial potential.

Aside from the tidal barrages (in which there is little interest in future development), there are no purely commercial ocean energy plants in operation. Thus, learning curves and cost figures for ocean energy systems do not reflect existing experience, but rely instead on estimates. For example, wave energy systems have seen 20 years of slow development. It has been shown that estimated electricity cost for oscillating water columns have decreased by a factor of four, from USD 0.5/kWh to USD 0.12/kWh. These estimates assume bulk production of components and perfect power plant behaviour, both of which have yet to be obtained. Available estimates of power cost for energy from off-shore wave devices are in the range of USD 0.10/kWh to USD 0.14/kWh. However, it should be noted that these estimates are not current; more recent figures place prices for tidal and marine current energy in the range of USD 0.055/kWh to USD 0.16/kWh.

Benefits: The environmental impact is low. There have been some concerns raised about tidal systems interfering with wetlands and basins, and concerns about interference with ocean transport have been raised for wave and current systems.

Economic viability is essential to attract investors and energy producers. It derives from the best compromise between an inexpensive design, a reliable design and the economic situation of a particular site. Predictability of power generation also plays a strong role. The most attractive combination is a good design that delivers reliability and ease of manufacture and deployment.

Lowering costs will improve the economic viability and acceptability of emerging ocean energy technologies. This aim is achieved through efficient design, the use of low-cost and readily available materials and components, and economies of scale. Safety is a crucial issue for any device in a marine environment and must concern both the device itself and all the sea users – human and non-human. To ensure security, deployment and construction procedures and accident prevention systems must be efficient, reliable and safe. Reliability is necessary to minimise the need to access the site for repairs and inspections, thereby helping to decrease the cost of operation.

Ensuring that ocean energy technologies have low environmental impact is a fundamental requirement to preserve the fragility of marine ecosystems and to truly be a clean energy source. All ocean energy systems must be designed with consideration of how the system will influence the environment in which it is placed – including the fact that ocean energy devices can have positive environmental impacts. An ocean energy farm consisting of multiple devices over a specified area could help create a wildlife sanctuary by restricting access to the site. In addition, marine life is known to thrive on man-made structures and wave energy systems could be integrated into coastal protection strategies.

Potential: Resource potential assessment provides information about how much energy is available and where it is accessible – and is the first step in enabling decision-making for device developers, deployment project sponsors, and policy makers. But the tool needs to be refined and extended. Past estimates for wave and tidal current technologies and for a wave energy resource atlas of Europe (1996), gave numbers for off-shore applications and according to the measurement and exploitation technologies available at the time. A number of developments during the past decade suggest that updated resource assessments are now necessary. The recent developments include:

- Improved measurement technologies and deeper knowledge in oceanography.
- New ocean energy concepts and devices that open new exploitation possibilities.
- Enhanced Earth observation satellites that dramatically improve capacity to measure the height (with one-metre precision) and physical properties of waves.
- Weather forecasting and climate change models that simulate patterns in wave generation and current behaviour.
- The advent of remote-sensed wave measurements for wave energy resource assessment, which promises to become a very important tool – particularly when coupled with mathematical modelling of waves.

To fully exploit the potential of these new technologies, ocean energy experts require more detailed knowledge of waves and tidal currents. They also need access to a database or an atlas showing energy available and including the following:

- Wave energy or current speed (depending on the device).
- Availability of grid connections.
- Availability of harbour facilities.
- Presence of natural reserves or restricted areas.

- Status of access to the site.

A new methodology may be needed to adapt currently available databases and new expertise may be required to complement existing knowledge on ocean energy. Such databases are now being compiled at the national level and should be expanded on a regional basis. The scope and universality of the proposed assessment will be limited only by the ambition applied and the resources assembled.

3.9. Renewable Energy Tomorrow

The future of renewable energy is affected by a number of factors, perhaps the first of which is technology. Renewables have experienced significant technological progress to improve reliability, efficiency and reduce overall costs, not only in the specific technologies themselves but also in the integration into grids, improving materials, modularity, better control systems etc. Hybrid systems provide one solution to help improve the market penetration of renewable energy technologies.

There is a push and pull effect that will crucially affect the future. There is a push by governments as they set policies to promote a more diversified and robust energy system. The renewable energy manufacturing industry is also setting targets and implementing measures to ensure that these targets are met. There is also the push from other policies, such as environmental protection, which indirectly support renewables by underpinning development of appropriate, clean technologies for the future. This redefining of the policy framework can provide strong support for renewables.

The pull comes from end users who are demanding more services. In some cases there is demand to introduce renewables based on the intuition or calculation of their benefits. In other cases the demand is for cheaper, more reliable, or cleaner energy production. There are many forms of expression for these needs. The future, however, is perhaps primarily a function of the value that is placed on such concepts as sustainable development, rural development and electrification, eradication of poverty, greater equity in providing energy services globally, diversification of the energy mix, and cleaning up the environment.

It is also important to look at the different technology areas in terms of their pathway to full market “take-off”. The paths that each of the technologies will follow are unique, but each is likely to achieve a point in the future where government intervention to achieve competitiveness with conventional technologies is no longer necessary. This market “take-off" can be seen as the transition point to broad acceptance of renewables as being competitive against conventional alternatives.

3.10. Renewable Energy Market

It can be said that there is the potential to achieve a greater share for renewables under the Alternative Case, if more vigorous policies are implemented. General policies to support renewables normally have limited effects because each renewable energy technology, as seen above, follows its own path of marketability according to its attributes, applications and state of technical development. It is believed that more targeted interventions will provide better impact.

It is very important issue how to effectively accelerate the market deployment of these technologies. Discussion focuses on market "takeoff", where further government support is not needed. A strategy must be unique for each technology area in order to reflect individual pathways and, conceivably, there will be sub-sets within technology areas because of the differing applications (e.g. for electricity generation or for heat).

The strategies generally follow five steps to achieve market acceleration and the sought after market "take-off." These include:

- ***Accelerate technology development:*** Even in the most advanced technologies, such as hydropower, further technology development will reduce costs to improve market competitiveness. Strategies are being developed concerning the R&D or demonstration projects that are needed, and who is best placed to undertake these activities.
- ***Strengthen national policy frameworks:*** For renewables to compete fairly, a policy framework must be established that rewards technologies for delivering on environmental, economic and social objectives, and penalizes those technologies that do not. As long as policy frameworks ignore environmental, economic, diversification and social goals in the calculus of competition, incentives to spur renewables are justified. However, a long-term policy framework that reflects and values sustainable development and objectives is a preferable environment to spur renewable growth.
- ***Reduce market barriers and industry startup costs:*** Barriers to renewables have arisen due to their emergence into the market while the characteristics of renewables are not yet reflected in policy mechanisms. For example, renewables were not well understood or appreciated when some international agreements were signed, raising

obstacles to renewables in otherwise important agreements. Similarly, important duties are sometimes applied, based on classifications developed for mature commercial products, not renewable energy. These barriers have a significant negative impact on renewables competitiveness and should be relatively easy to remove. Transitional overheads include all initial cost elements to develop the infrastructure to support commercial products in a national market. Once these investments are made, they do not need to be repeated, as they are typically "start-up costs". Targeted national policies to mitigate these costs would boost potential market growth. Examples include assessing market potential, completing exploration and pre-feasibility activities (e.g. in the case of geothermal), investing in new transmission lines where needed to connect renewables to the grid, and examining the possibilities for new financing and insurance instruments to decrease induced risk and reduce the cost of capital in project cash flows.

- ***Mobilise market investment:*** Many of the technologies need greater participation from the private sector. More effort can be made to attract private sector financing by increasing the visibility of the technologies and providing information on market opportunities and conditions. There are cases where this is working, e.g. the private sector is taking much of the lead in PV technology.
- **Promote international cooperation:** Bringing together a number of like-minded countries that wish to develop a specific resource can strengthen markets. By combining forces even more than is occurring today, project and infrastructure costs could be reduced significantly. International cooperation can also play an important role in developing technical standards as well as RD&D. In effect, international cooperation ensures more efficient use of all human and financial resources. International cooperation can strengthen capacity building in developing countries as well as supplying business and technology components needed to develop and maintain projects. International cooperation can also mobilise investments through such mechanisms as the Clean Development Mechanism or many of the renewable energy funds set up by the international finance institutions.

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CHAPTER 4

IMPORTANCE OF RENEWABLE ENERGY SOURCES FOR EUROPE

4.1. Introduction

Sustainable development can be broadly defined as living, producing and consuming in a manner that meets the needs of the present without compromising the ability of future generations to meet their own needs. It has become a key guiding principle for policy in the 21st century. In the international context, the word ‘development’ refers to improvement in quality of life, and, especially, standard of living in the less developed countries of the world. The aim of sustainable development is for the improvement to be achieved whilst maintaining the ecological processes on which life depends. The concept of sustainable development became widely accepted following the seminal report of the World Commission on Environment and Development (1987). The commission was set up by the United Nations because the scale and unevenness of economic development and population growth were, and still are, placing unprecedented pressures on our planet’s lands, waters and other natural resources. Some of these pressures are severe enough to threaten the very survival of some regional populations and, in the longer term, to lead to global catastrophes. Changes in lifestyle, especially regarding production and consumption, will eventually be forced on populations by ecological and economic pressures. Nevertheless, the economic and social pain of such changes can be eased by foresight, planning and political (i.e. community) will. Energy sources exemplify these issues.

Reliable energy supply is essential in all economies for lighting, heating, communications, computers, industrial equipment, transport, etc. Purchases of energy account for 5–10% of gross national product in developed economies. However, in some developing countries, energy imports may have cost over half the value of exports; such economies are unsustainable and an economic challenge for sustainable development. World energy use increased more than tenfold over the 20th century, predominantly from fossil fuels (i.e. coal, oil and gas) and with the addition of electricity from nuclear power. In the 21st century, further increases in world energy consumption can be expected, much for rising industrialisation and demand in previously less developed countries, aggravated by gross inefficiencies in all countries [1].

There are no doubts about the non-sustainability of our fossil fuel based current energy system. The problems related to energy may be classified as below:

- depletion of fossil fuel resources,
- growth in population and energy demand,

- global warming (climate change),
- global unrest,
- local pollution,
- fluctuating oil and natural gas prices etc.

Fossil fuel reserves are diminishing rapidly across the world, intensifying the stress on existing reserves day-by-day due to increased demand (see Table 4.1). Fossil fuels and uranium are not being newly formed at any significant rate, and thus present stocks are ultimately finite. The location and the amount of such stocks depend on the latest surveys. Clearly the dominant fossil fuel type by mass is coal, with oil and gas much less. The reserve lifetime of a resource may be defined as the known accessible amount divided by the rate of present use. By this definition, the lifetime of oil and gas resources is usually only a few decades; whereas lifetime for coal is a few centuries.

Economics predicts that as the lifetime of a fuel reserve shortens, so the fuel price increases; consequently demand for that fuel reduces and previously more expensive sources and alternatives enter the market. Current and future markets in fossil fuels are subject to volatile price changes in oil and natural gas. There are many national and international crisis and conflicts around energy sources [2].

In practice, many other factors are involved, especially governmental policy and international relations. Nevertheless, the basic geological fact remains: fossil fuel reserves are limited and so the present patterns of energy consumption and growth are not sustainable in the longer term. The world's population is forecast to grow by 2.5 billion by 2050, reaching a total of some 9.2 billion. In addition, many economies are currently experiencing rapid expansion and industrialisation. As population grows and industry expands, so does the demand for energy. If governments around the world maintain their current policies, the world's energy needs may increase by 50% or more by 2030. In the past, these needs have been satisfied largely by finite energy sources. These will be exhausted in the future [3].

Not only depletion time of fossil fuel reserves and their prices are problems we face but also their combustions cause some environmental problems. Of late environmental pollution has started to make its impact felt across the world. Moreover, currently more than 80% of the world’s energy supply comes from fossil fuels, with serious ecological and environmental consequences [2].

Table 4.1. Proved reserves and expected depletion lifetimes of primary fossil based energy sources [4]

Primary Energy Source	Year		R/P*
	2006	2007	
Oil (thousand million barrels)	1239.5	1237.9	41.2
Natural Gas (trillion cubic meters)	176.22	177.36	60.3
Coal (million tonnes)	909064	847488	133

*Reserves/Production (R/P) ratio - If the reserves remaining at the end of the year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that rate

Global warming driven by energy usage, in particular the production of greenhouse gas emissions, directly impact the environment. Environmental issues span a continuously growing range of pollutants, hazards and ecosystem degradation factors that affect areas ranging from local through regional to global. Some of these concerns arise from observable, chronic effects on, for instance, human health, while others stem from actual or perceived environmental risks such as possible accidental releases of hazardous materials [5].

Both the population and anthropogenic activities have caused considerable damage to the ecological balance and the environment as a whole. In the past decades conventional pollutants (i.e. SO_2, NOx, CO and particulates) have been subjected to control provisions and mechanisms. Recently global pollutants like CO_2 emissions has been given top priorities as the level rise in concentration of CO_2 is the primary contribution to the global warming [6]. About half of greenhouse gases which rise the earth's temperature due to the emissions of gases into the atmosphere are emitted by burning the fossil fuels.

Most important greenhouse gas is water vapour, but human effects on rise in water vapour level are very little. Water vapour is produced naturally or depends on other greenhouse gases levels, especially CO_2 [7]. Carbon dioxide is the most important greenhouse gas with significant man-made sources, about 40% of the total (fossil fuels, land use, deforestation etc.). It is also produced naturally through respiration of plants and animals. Figure 4.1 represents how the various greenhouse gases have contributed to the enhanced greenhouse effect or global warming during the last 200 years.

Greenhouse gases--especially CO_2 produced by the combustion of fossil fuels as seen in Figure 4.1--cause global warming, and affect climate conditions worldwide. Before the industrial era, the natural concentration of CO_2 was estimated to be about 280 ppm; since that time there has been an increase of about 30%--up to 386 ppm by mid-2007 [8,9]. This increase, and consequent temperature rise, has been attributed largely to energy use, and mainly from fossil fuels. These contributions are the result of higher summer temperatures, warmer winter, temperatures, flooding, increases in vector-borne diseases, and so on. The health costs of increased greenhouse-gas emissions are difficult to estimate and are controversial. A WHO (World Health Organization) study has estimated that the increase in greenhouse gases since 1990 has resulted in around 150000 excess deaths in 2000 [10].

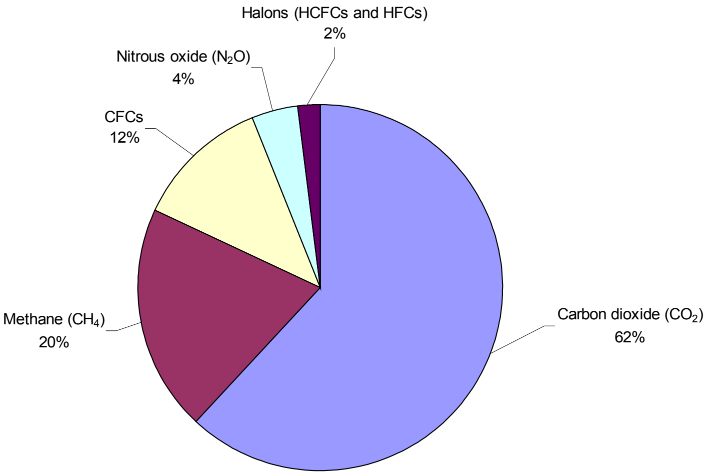

Figure 4.1. Contributions of the main greenhouse gases to global warming during the last 200 years [7].

Fossil fuels are mainly used for electricity production, heat generation and transportation. The global electricity supply sector accounts for the release to the atmosphere of over 7700 million tonnes of carbon dioxide annually, being 37.5% of total CO_2 emissions [11].

In December 1997, the representatives of 160 countries gathered in Kyoto at the United Nations Framework Convention on climate change to discuss targets for reductions in greenhouse gas emissions, especially CO_2. The resulting ‘Kyoto protocol’ has called for the ‘Annex I countries’ to reduce the average of their individual emissions by at least 5% below 1990 levels in the period 2008–2012. The specific targets proposed for the key industrial powers of the European Union, Japan and USA are 7, 6 and 8%, respectively [12].

A secure and accessible supply of energy is very crucial for the sustainable development which can be defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Many factors contribute to achieving sustainable development. One of the most important things is the requirement for a supply of energy sources that is fully sustainable [13]. Therefore, it is compulsory to look for alternative-renewable sources and fuels.

A greater use of renewable energy can also have other positive effects, such as [14]:

- increased energy diversity and security (through increased use of indigenous energy supplies),
- income generation from the export of new technologies,
- employment (renewable energy technologies are often labour-intensive),
- maintaining rural population levels (via incentives for biomass energy), and
- decentralizing electricity supply.

4.2. Energy Policy of European Union

Oil shocks and crisis in 1970s, their impact on the economic and monetary system at international and Europe level, some efforts to reduce its dependence on imported oil are the closely interrelated problems which topped the economic agenda. The Community was ill prepared to cope with these problems, for when the founding Treaties were signed in the 1950s, it was almost self-sufficient in energy and hoped that a new source - atomic energy - would soon take over from coal, the traditional source. Time proved otherwise and it was oil which made a spectacular entry onto the Community market in the1960s [15].

In that two Community Treaties dealt uniquely with the energy of the past (coal - ECSC) and the perceived one of the future (nuclear - Euratom), the Commission did not have the legal instruments at its disposal to assume responsibilities in the energy sector (oil - EEC) which had since become the dominant player. The Community perceived the risks of its dependence from imported oil during the October 1973 energy crisis. From 1974 onwards, Community objectives began to be defined and steps taken to reduce dependence on imported crude oil and petroleum products. It was from this point that a common energy policy began to take shape at a snail's pace [15].

While respecting the subsidiarity principle and the environmental requirements for sustainable development, European energy policy aims, therefore, at influencing energy production and consumption with the objective of securing economic growth and safeguarding the wellbeing of the citizens of the Union. It must, on the one hand, ensure the smooth functioning of the single market in energy products and services and, on the other, guarantee the supply of relatively cheap and secure (from the strategic and environmental viewpoints) energy sources to the States of the Union. The common energy policy thus revolves around two axes: the functioning of the internal energy market and the security of energy supplies.

In the 1950s coal was in abundant supply, was relatively inexpensive and met 65% of the energy requirements of the six founding countries. It was therefore seen as the energy, which would fuel the creation of the common market. Furthermore, impressed by the recent demonstration at Hiroshima of the force of atomic energy, experts were predicting a bright future for its peaceful use.

No clear need for a common or even national oil policy was perceived in the years when oil was cheap and supply certain, which was the case throughout the post-war years up to the early 1970s. This golden era was anchored in major oil discoveries by Western oil companies in the Middle East and Africa and in the legal system governing the exploitation of oil reserves. The central principle of this system was the granting of a prospecting and working monopoly over a given area by the producer country to one or several foreign companies (licence). The activity spectrum of these companies covered all of the petroleum industry activities (prospecting, production, transport, refining, storage and distribution) and they enjoyed a strong position enabling them, in the vast majority of exporting countries and in relation to most of the importing countries, to regulate petroleum output and marketing terms.

Although the Governments of the then six Member States showed a clear tendency towards an "every man for himself" policy, they nevertheless approved a "Protocol of Agreement on Energy Problems" in April 1964. In this Protocol, they stated their commitment to the development and implementation of a Community energy policy, without considering it necessary to set a time limit for its definition. Time was however running against them, for world oil demand grew more rapidly than supply and around 1970 the market changed from a buyer's to a seller's one. Oil-producing countries became aware of the power which they wielded and changed their attitude towards consumer countries and oil companies. The calm which had reigned in the oil sector during most of the post-war period was suddenly shattered in 1970 and replaced by an incessant stream of demands by producing countries, by agreements concluded and broken and finally by a mad rush for self-survival among consumer countries.

Very few specific measures were adopted in the oil sector until the crisis hit this sector. Among the rare few was one on the obligation of the Member States to maintain minimum stocks of petroleum products as a security measure [Decision 68/416] and one on the notifying of the Commission of investment projects of interest to the Community in the petroleum, natural gas and electricity sectors [Regulation 1056/72 repealed by Regulation 736/96]. Special mention must be made of a Directive adopted by the Council in July 1973, just a few months before the October 1973 crisis, urging the Member States to take measures, appoint bodies and prepare intervention plans to mitigate the effects of possible supply restrictions [Directive 73/238].

4.2.1. Energy Security

In the Member States, the first effect of the crisis was a shortage of oil, which led to a number of measures to restrict consumption (no use of cars on Sundays, speed limits, heating restrictions and so on). As shortage fears diminished, prices and their financial consequences became the uppermost concern. Although supply difficulties tailed off after December 1973, the prices for crude oil kept growing to reach twelve times their pre-crisis level (36 dollars the barrel compared to 3) after the second oil-shock provoked by the Iran-Iraq war of 1980. This abrupt increase in crude oil prices in the space of six years dealt a devastating blow to the economies in several regions of the world, including Europe. The Community Member States, accustomed to trade surpluses, saw these frittered away into a deficit situation.

Aside from these economic consequences, the 1973 crisis created a sense of insecurity among the European countries, and rightly so, for it revealed the vulnerability of their economies due to their dependence on available quantities and price levels of the vital fuel, oil. The cartel of producer countries inspired much less confidence than its predecessor, the cartel of the "seven sisters" (Exxon, Shell, B.P., Mobil, Texaco, Chevron and Gulf). The concept of everyone settling their own affairs and entrusting multinational oil companies with the common good took a serious blow when the seven sisters and their poorer relations such as Total, Elf and Agip lost ownership of their crude oil resources and were therefore unable to continue guaranteeing the supply security of Europe. This awareness of the Community's energy vulnerability led to the need for a coherent system of external relations to guarantee supply security.

The 1973 crisis gave rise to several initiatives seeking to establish "dialogue" between oil producer and consumer countries. There are occasional meetings between the European Commission and the secretariats of the Organisation of Petroleum Exporting Countries (OPEC) and the Organisation of Arab Petroleum Exporting Countries (OAPEC), which discuss oil trade, the situation on the international energy market and the interest of all, consumers and producers alike, in avoiding too large price fluctuations. This dialogue is certainly useful, but cannot in itself lay the foundation for cooperation between the European Union and energy producing countries, notably the Gulf countries where the World's most important hydrocarbon reserves are located.

Pan-European cooperation in the energy field is assisted by the Instrument for Pre-Accession Assistance (IPA) and by the European Neighbourhood and Partnership Instrument (ENPI) for candidate and other neighbouring countries. Technical assistance programmes in the energy field cover the drafting and planning of energy policy in these countries, energy supply and demand, tariff system and pricing, energy savings, the interconnection of East-West networks, training, environmental protection, the reshaping of the energy industry and nuclear safety. Agreements between the European Atomic Energy Community (Euratom) and the Russian Federation in the field of nuclear safety and in the field of controlled nuclear fusion provide for cooperation between the parties concerning reactor safety research, radiation protection, nuclear waste management, decommissioning, decontamination and dismantling of nuclear installations, and research and development on accountancy and control of nuclear material [Agreement on nuclear fusion, Agreement on nuclear safety and Decision 2001/761]. A multilateral environmental programme and a protocol establish a coherent legal framework for implementing nuclear-related projects in the Russian Federation [Framework Agreement, Protocol and Decision 2003/462].

The European Energy Charter attempts to put some order in energy supply and demand conditions in Europe. It lays down the principles, the objectives and ways of achieving pan-European cooperation in the field of energy. Signed in the Hague on December 17, 1991 by almost all European countries as well as by the Community [Decision 98/181], Canada, the United States, and Japan, the Charter is in fact a code of good practice. Its interest is to give the first tangible demonstration of a consensus based upon solidarity and complementarity, in particular between the countries of Western Europe - with their know-how and advanced technologies - and those of Central and Eastern Europe, including the countries of the former Soviet Union, which have relatively abundant energy resources.

The Charter pursues the following operational objectives: expansion of trade, especially through free market operation, free access to resources and the development of infrastructure; cooperation and coordination of energy policies; and the optimal use of energy and protection of the environment. These objectives should be attained through the implementation of joint measures by the signatory countries in six specific priority fields: access to resources; use of resources; investment arrangements; liberalisation of trade; harmonisation of technical specifications and safety rules; research and technological development and innovation.

The implementation of the Charter is provided by the European Energy Charter Treaty , signed in Lisbon on 17 December 1994 [Final Act of the Conference, Annex 1, Annex 3 and Decision 94/998, Amendment to the Treaty, Decision 98/537 and Decision 2001/595]. This Treaty is designed to develop new relations between the main European countries, most of the independent States of the former Soviet Union and Central and Eastern Europe, Canada, the United States and Japan concerning the transit of energy products between east and west, trade, investment and energy cooperation. The European Commission assists the Secretariat of the Conference, which is established in Brussels. The practical implication of the Energy Charter is the diversification of the supplies of European Union countries in oil and natural gas and, hence, their decreasing dependence from Middle Eastern sources. Russia has signed but not ratified the Energy Charter Treaty and the Partnership and Cooperation Agreement between the EU and Russia (signed in 1994 and in force since 1997) has not solved the energy problems between the two parties. Therefore an energy dialogue was deemed necessary to resolve energy questions. Since its launch in 2000, the energy dialogue between the European Union and Russia has resolved a number of difficulties between the two parties. It has contributed to the smooth operation of the internal market, sustainable development with the ratification by the Russian Federation of the Kyoto Protocol, and the security of energy supply. This exchange has also resolved important questions such as the preservation of long-term supply contracts and the abolition of measures which are contrary to Community competition rules. European and Russian companies investing in the energy sector have benefited from this dialogue, which thus helps the creation of a pan-European energy market.

On 25 October 2005, the EU and eight partners in south-east Europe (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Former Yugoslav Republic of Macedonia, Romania, Serbia and Montenegro and UNMIK, on behalf of Kosovo) signed the Energy Community Treaty in order to create the legal framework for an integrated energy market [Decision 2006/500 and Treaty]. The main objectives of this treaty are to create: a stable market framework capable of attracting investment in order to ensure a stable and continuous energy supply; and a single regulatory space for trade in network energy (electricity and gas). As a result of this treaty, the EU internal market for energy will be extended into the Balkan peninsula as a whole. This means that the relevant acquis communautaire on energy, environment and competition will be implemented there. Market opening, investment guarantees and firm regulatory control of the energy sectors will also be enhanced [15].

4.2.2. The Other Problems and Some Actions

European energy markets face a number of problems: the growing threats of climate change, slow progress in energy efficiency and the use of renewables, the need for transparency, further integration and interconnection of national energy markets and the need for large investments in energy infrastructure. Moreover, Europe has to deal with major challenges in energy supply: the ongoing difficult situation on the oil and gas markets, the increasing import dependency and limited diversification achieved so far, high and volatile energy prices, growing global energy demand, security risks affecting producing and transit countries as well as transport routes.

The " Intelligent Energy - Europe " programme, which is part of the competitiveness and innovation framework programme (CIP, 2007-2013) contributes to achieving the general objectives of improving energy diversification and security of supply, and enhancing the competitiveness of companies in the Union while protecting the environment and meeting international commitments in this area. It finances promotion programmes at Community level aiming at creating the conditions for moving towards sustainable energy systems, at supporting the standardisation of equipment which produces or consumes renewable energy sources, at increasing technology deployment and at spreading best practices in demand side management. This programme continues three actions established by Decision 1230/2003 aiming at: (i) promoting energy efficiency and the rational use of energy sources (SAVE); (ii) promoting new and renewable energy sources (ALTENER); and (iii) promoting energy efficiency and the use of new and renewable energy sources in transport (STEER).

In a 2006 Green Paper the Commission defines a European energy policy, which should aim at three major objectives: sustainable development, competitiveness and security of supply. The Green Paper was followed by a Commission communication, which states that the point of departure for a European energy policy is threefold: combating climate change, promoting jobs and growth, and limiting the EU's external vulnerability to gas and oil imports. The mainstay of the new energy policy, approved by the Brussels European Council (8-9 March 2007), is a core energy objective for Europe: to reduce greenhouse gas emissions from its energy consumption by 20% by 2020. To achieve this objective, the Commission proposed to focus on a number of energy-related measures: improving energy efficiency; raising the share of renewable energy in the energy mix, as well as new measures to ensure that the benefits of the internal energy market reach everyone; reinforcing solidarity among Member States, with a more long-term vision for energy technologies development, a renewed focus on nuclear safety and security, and determined efforts for a common external energy policy enabling the EU to speak with one voice with its international partners, including energy producers, transit and high energy-consumers and developing countries [15].

4.3. Renewable Energy Policy of Europe

The European Union faces major challenges concerning climate change, security of energy supply, and the need to increase market competitiveness. Energy demand is steadily increasing and dependence on fossil fuels from outside the European Union is growing, at a time of fiercer competition on the global energy markets, inevitably pushing up energy prices. The main factor driving the underlying growth in energy demand is economic growth. Current policy analyses show that greenhouse gas (GHG) emissions are rising. The risks and costs related to climate change are many: increasing natural disasters worldwide, flooding, and countries being submerged. The costs of catastrophes are high and the costs of adaptation are potentially large. Combating climate change will require substantial reductions in GHG emissions, which means switching to low-carbon energy and reducing energy consumption. The challenge of climate change is coupled with the challenge of increased dependence on imports of fossil fuels. The current rate of import dependency is expected to rise from about 50% to 70% over the next 30 years. Import dependency, combined with the increasingly volatile world energy market, increases uncertainty of energy supply and the risks of supply disruption. These developments are inflationary and economically destabilising and have an adverse impact on economic growth and investment. The instability of the world energy market has geopolitical consequences and imposes costs on energy importing countries. Despite numerous ongoing energy efficiency efforts, energy consumption growth is still a cause of concern [16].

Renewable energy sources will play an increasingly important role in securing both the Union’s energy supply and sustainable development in the future. Renewable energy sources have the potential to tackle these environmental and economic problems. These sources are currently unevenly and insufficiently exploited in the European Union and candidate states. Although many renewable energy sources are abundantly available, and the real economic potential considerable, renewable energy make a disappointingly small contribution of less than 7% to the Union’s overall gross inland energy consumption, which is predicted to grow steadily in the future.

Renewable energy sources are indigenous, and can therefore contribute to reducing dependency on energy imports and increasing security of supply. Development of renewable energy sources can actively contribute to job creation, predominantly among the small and medium sized enterprises which are so central to the Community economic fabric, and indeed themselves form the majority in the various renewable energy sectors. Deployment of renewables can be a key feature in regional development with the aim of achieving greater social and economic cohesion within the Community. The expected growth in energy consumption in many third countries, in Asia, Latin America and Africa, which to a large extent can be satisfied using renewable energies, offers promising business opportunities for European Union industries, which in many areas are world leaders as regards renewable energy technologies. The modular character of most renewable technologies allows gradual implementation, which is easier to finance and allows rapid scale-up where required. Finally, the general public favours development of renewables more than any other source of energy, very largely for environmental reasons [17].

The European Commission published a White Paper in 1997 setting out a Community strategy for achieving a 12% share of renewables in the EU’s energy mix. The decision was motivated by concerns about security of supply and environmental protection. The 12% target was adopted in a 2001 directive on the promotion of electricity from renewable energy sources, which also included a 22.1% target for electricity for the EU-15. The legislation was an important part of the EU's measures to deliver on commitments made under the Kyoto Protocol. Nevertheless, the targets were not binding and it became evident that they would not be met.

In January 2007, the Commission published a Renewable Energy Roadmap outlining a long-term strategy. It called for a mandatory target of a 20% share of renewable energies in the EU's energy mix by 2020. The target was endorsed by EU leaders in March 2007. To achieve this objective, the EU adopted a new Renewables Directive in April 2009, which set individual targets for each member state [18].

In addition, there are important job creation benefits from a strategy for greater promotion of renewable energy technologies. Employment is created at different levels, from research and manufacturing to services, such as installers and distributors. Renewable energy has created more than 14 million jobs worldwide; every renewable energy industry is rapidly expanding its workforce [19].

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