Energy Sources, Part B, 4:212–224, 2009

ISSN: 1556-7249 print/1556-7257 online
DOI: 10.1080/15567240701620499

Taylor & Francis
Taylor & Francis Group

Global Renewable Energy Projections

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Abstract *Projections are important tools for long-term planning and policy settings. Renewable energy sources that use indigenous resources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. Currently, renewable energy sources supply 14% of the total world energy demand. Renewable energy is a promising alternative solution because it is clean and environmentally safe. Approximately half of the global energy supply will be from renewables in 2040. Photovoltaic systems and wind energy will be able to play an important role in the energy scenarios of the future. The most significant developments in renewable energy production are observed in photovoltaics (from 0.2 to 784 Mtoe) and wind energy (from 4.7 to 688 Mtoe) between 2001 and 2040. Biomass is the most used renewable energy source now and in the future. The potential of sustainable large hydro is quite limited to some regions in the world. The potential for small hydro (<10 MW) power is still significant and more significant in future. Photovoltaic systems and wind energy are technologies with annual growth rates of more than 30% during the last years that will become more significant in the future. Geothermal and solar thermal sources are more important energy sources for the future. Photovoltaics will then be the largest renewable electricity source with a production of 25.1% of global power generation in 2040.*

Keywords bioenergy, photovoltaic, renewable energy, solar energy

Introduction

There are mainly three energy sources: fossil, renewable, and fissile. The fossil energy sources are petroleum, coal, natural gas, bitumens, oil shales, and tar sands; the renewable energy sources covered are biomass, solar, wind, geothermal, and hydropower; and the fissile energy sources are uranium and thorium.

Known petroleum reserves are estimated to be depleted in less than 50 years at the present rate of consumption (Sheehan et al., 1998). Oil is a finite resource. Various studies put the date of the global peak in oil production between 1996 and 2035. In developed countries, there is a growing trend towards employing modern technologies and efficient bioenergy conversion using a range of bio-fuels, which are becoming cost-wise competitive with fossil fuels (Puhan et al., 2005).

Energy production from fossil fuels results in high greenhouse gas emissions. Global utilization of fossil fuels or energy needs is rapidly resulting in critical environmental problems throughout the world. The availability of fossil fuels, renewable energy sources, and nuclear sources strongly affects current and future energy supply systems. Declining availability of fossil fuels may cause increases in fuel prices and declining security

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of energy supply in the current energy system. Limited availability of fossil fuels and renewable energy sources on a local scale may affect the sustainability of future energy systems. If the global growth rate of about 2% a year of primary energy use continues, it will mean a doubling of energy consumption by 2035 relative to 1998, and a tripling by 2055 (UNDP, 2000).

The global and regional availability has been estimated for wind energy; solar energy, especially photovoltaic (PV) cell; and biomass; together with a description of factors influencing this availability. On the long term, countries with surplus biomass potential could develop into exporters of bioenergy.

Renewable energy sources or renewables contributed 2% of the world's energy consumption in 1998, including 7 exajoules from modern biomass and 2 exajoules for all other renewables (UNDP, 2000). The renewables are clean or inexhaustible and primary energy resources. Renewable technologies like water and wind power probably would not have provided the same fast increase in industrial productivity as fossil fuels did (Edinger and Kaul, 2000).

Oil and gas are expected to continue to be important sources of energy (Nakicenovic et al., 1998). The share of renewable energy sources is expected to increase very significantly (to 30–80% in 2100). Hydropower and traditional biomass are already important factors in the world's energy mix, contributing about 18% of the total world energy requirements, whereas the renewables contribute only about 2% of the present world primary energy use. Biomass, wind, and geothermal energy are commercially competitive and are making relatively fast progress (Fridleifsson, 2001).

Global Energy Sources and Present Energy Situation

Fossil fuels still represent over 80% of total energy supplies in the world today, but the trend towards new energy sources is clear in the future thanks to the new technological developments.

Oil is the fossil fuel that is most in danger to become short in supply. The Middle East is the dominant oil province of the world, covering 63% of the global reserves. Figure 1 shows global oil production scenarios based on today's production. A peak in global oil production may occur between 2015 and 2030. Countries in the Middle East

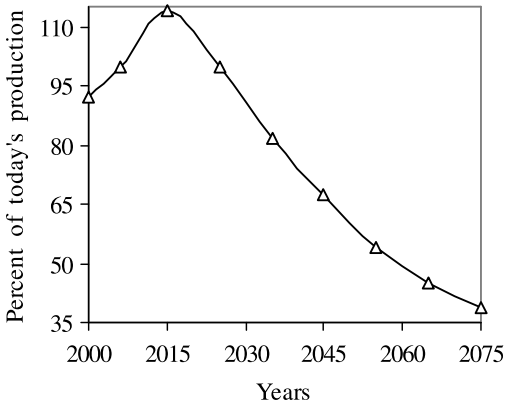

Figure 1. Global oil production scenarios based on today's production.

and the Russian Federation hold 70% of the world's dwindling reserves of oil and gas. Geographical distribution of energy reserves and resources is important.

The worldwide coal production is roughly equal to the gas production and only second to that of oil. Coal is produced in deep mines (hard coal) and in surface mines (lignite). Coal has played a key role as a primary source of organic chemicals as well as a primary energy source. Coal may become more important both as an energy source and as the source of carbon-based materials, especially aromatic chemicals in the 21st century (Schobert and Song, 2002). Coal accounted for 26% of the world's primary energy consumption and 37% of the energy consumed worldwide for electricity generation (Demirbaş, 2006a).

Table 1 shows the recoverable coal reserves in 1999 and the world's coal production and consumption in 1998. The worldwide coal production and consumption in 1998 were 5,043 and 5,014 million short tons, respectively. The known world recoverable coal reserves in 1999 are 1,087 billion short tons (AER, 1999; IEA, 2000). Coal reserves are rather evenly spread around the globe: 25% are in the USA, 16% in Russia, and 11.5% in China. Although coal is much more abundant than oil and gas on a global scale, coalfields can be depleted in a region.

Coal's role in energy use worldwide has shifted substantially over the decades, from a fuel used extensively in all sectors of the economy to one that is now used primarily for electricity generation and in a few key industrial sectors, such as steel, cement, and chemicals (Demirbaş, 2001a). In 1995, coal accounted for 26% of the world's primary energy consumption and 37% of the energy consumed worldwide for electricity generation (UNDP, 2000).

The role of natural gas (NG) in the world's energy supply is growing rapidly. NG is the fastest growing primary energy source in the world. The reserves and resources of conventional NG are comparable in size to those of conventional oil, but global gas consumption is still considerably lower than that of oil. The proved gas reserves are not evenly distributed around the globe: 41% of them are in the Middle East and 27% of them are in Russia. A peak in conventional gas production may occur between 2020 and 2050. NG accounts today for 25% of the world's primary energy production (Jean-Baptiste and Ducroux, 2003). Because it is a cleaner fuel than oil or coal and is not as controversial as nuclear power, gas is expected to be the fuel of choice for many countries in the future (Demirbaş, 2001b). Increasing demand for NG is expected in all sectors of the world, as

Table 1
Recoverable coal reserves in 1999 and world's coal production and consumption in 1998

Country	Recoverable reserve (1999), billion ton	Percentage	Production/consumption (1998), million ton
USA	271.8	25.0 20	—
Russia	173.9	16.0	—
China	125.0	11.5	—
Others	516.3	47.5	—
World	1,087.0	100	5,043/5,014

resource availability, rate, and environmental considerations all favor its use. World NG reserves by country are given in Table 2.

Nuclear power plants are based on uranium mined in surface mines, or by in situ leaching. Nuclear energy has been used to produce electricity for more than half a century. Worldwide, nuclear energy accounts for 6% of energy and 16% of electricity and 23% in OECD countries (UNDP, 2000). OECD countries produce almost 55% of the world's uranium. Fossil fuels; oil, coal, and gas currently provide more than two-thirds of the world's energy and electricity, but also produce the greenhouse gases largely responsible for global warming. The nuclear energy consumption in the world increased rapidly from 0.1% in 1970 to 7.4% in 1998. This increase was especially high in the 1980s (Demirbaş, 2005a).

Renewable energy sources that use indigenous resources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. Currently, renewable energy sources supply 14% of the total world energy demand. Large-scale hydropower supplies 20% of global electricity. Renewable resources are more evenly distributed than fossil and nuclear resources (Demirbaş, 2006a). Renewable energy scenarios depend on environmental protection, which is an essential characteristic of sustainable developments.

For biomass resources, several potentials may be used. Biomass resources are agricultural and forest residues, algae and grasses, animal manure, organic wastes, and biomaterials (Hoogwijk, 2004; Demirbaş, 2007). The supply is dominated by traditional biomass used for cooking and heating, especially in rural areas of developing countries. World production of biomass is estimated at 146 billion metric tons a year, mostly wild plant growth (Cuff and Young, 1980). Worldwide biomass ranks fourth as an energy resource, providing approximately 14% of the world's energy needs (Hall et al., 1992; Ramage and Scurlock, 1996).

Biomass now mainly represents only 3% of primary energy consumption in industrialized countries. However, much of the rural population in developing countries, which

Table 2
World natural gas reserves by country

Country	Percent of world total
Russian Federation	33.0
Iran	15.8
Qatr	5.8
United Arab Emirates	4.1
Saudi Arabia	4.0
United States	3.3
Venezuela	2.8
Algeria	2.5
Nigeria	2.4
Iraq	2.1
Turkmenistan	2.0
Top 20 countries	89.0
Rest of world	11.0

Source: Yazici and Demirbaş, 2001.

represents about 50% of the world's population, is reliant on biomass, mainly in the form of wood for fuel (Ramage and Scurlock, 1996). In Europe, North America, and the Middle East, the share of biomass averages 2–3% of the total final energy consumption, whereas in Africa, Asia, and Latin America, which together account for three-fourths of the world's population, biomass provides a substantial share of the energy needs: a third on average, but as much as 80–90% in some of the poorest countries of Africa and Asia (e.g., Angola, Ethiopia, Mozambique, Tanzania, Democratic Republic of Congo, Nepal, and Myanmar). Large-scale hydro power provides about one-fourth of the world's total electricity supply, virtually all of Norway's electricity and more than 40% of the electricity used in developing countries. The technically usable world potential of large-scale hydro is estimated to be over 2,200 GW.

There are two small-scale hydropower systems: micro hydropower systems (MHP) with capacities below 100 kW and small hydropower systems (SHP) with capacity between 101 kW and 1 MW. Large-scale hydropower supplies 20% of global electricity. In developing countries, considerable potential still exists, but large hydropower projects may face financial, environmental, and social constraints (UNDP, 2000).

Geothermal energy for electricity generation has been produced commercially since 1913, and for four decades on the scale of hundreds of MW both for electricity generation and direct use. The utilization has increased rapidly during the last three decades. In 2000, geothermal resources have been identified in over 80 countries and there are quantified records of geothermal utilization in 58 countries in the world. Table 3 shows the status of geothermal energy.

Geothermal energy is clean, cheap, and renewable, and can be utilized in various forms such as space heating and domestic hot water supply, CO_2 and dry-ice production process, heat pumps, greenhouse heating, swimming and balneology (therapeutic baths),

Table 3
World's top countries using geothermal energy in direct uses

Country	Installed, MWt	Production, GWh/a
China	2,282	10,531
Japan	1,167	7,482
USA	3,766	5,640
Iceland	1,469	5,603
Turkey	820	4,377
New Zealand	308	1,967
Georgia	250	1,752
Russia	308	1,707
France	326	1,360
Sweden	377	1,147
Hungary	473	1,135
Mexico	164	1,089
Italy	326	1,048
Romania	152	797
Switzerland	547	663

Source: Fridleifsson, 2002.

industrial processes, and electricity generation. The main types of direct use are bathing, swimming, and balneology (42%), space heating (35%), greenhouses (9%), fish farming (6%), and industry (6%) (Fridleifsson, 2001).

One of the most abundant energy resources on the surface of the earth is sunlight. Today, solar energy has a tiny contribution in the world's total primary energy supply of less than 1% (Ramachandra, 2007). The potential of solar energy—passive solar heat, collectors for e.g., hot water, and photovoltaic (PV) power—is tremendous.

Following the oil crises of the 1970s, energy experts began to explore whether solar-based power generation held potential as an alternative petroleum-based fuel. Development of solar power has progressed considerably since then, yet its record of performance has been mixed, and it has not come into widespread use in either industrialized or developing countries.

PV systems, other than solar home heating systems, are used for communication, water pumping for drinking and irrigation, and electricity generation. The total installed capacity of such systems is estimated at about 1,000 kW. A solar home heating system is a solar PV system with a maximum capacity of 40 W. These systems are installed and managed by a household or a small community (Garg and Datta, 1998).

Like wind power markets, PV markets have seen rapid growth and costs have fallen dramatically. The total installed capacity of such systems is estimated at about 1,000 kW. Solar PV is growing fast, the PV and grid-connected wind installed capacities are growing at a rate of 30% a year (Demirbaş, 2005b). Figure 2 shows the world PV module shipments from 1990 to 2000.

Wind energy is a significant resource; it is safe, clean, and abundant. Wind energy is an indigenous supply permanently available in virtually every nation in the world. Using the wind to produce electricity by turning blades on a wind turbine is called wind energy or wind power. More recently, large wind turbines have been designed that are used to generate electricity. Wind source of energy is non-polluting and freely available in many areas. As wind turbines are becoming more efficient, the cost of the electricity they generate is falling.

Wind power in coastal and other windy regions is promising as well. Today there are wind farms around the world. Production of wind-generated electricity has risen from practically zero in the early 1980s to more than 7.5 TWh per year in 1995. Cumulative generating capacity worldwide has topped 6,500 MW in late 1997 (Demirbaş, 2005b).

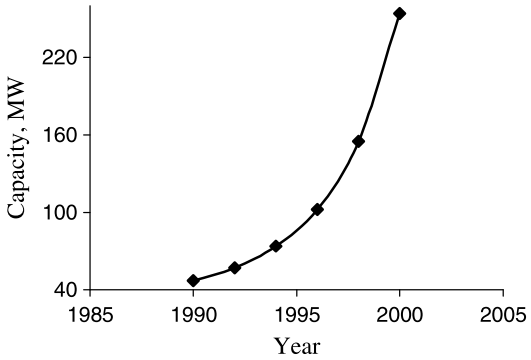

Figure 2. World PV module shipments from 1990 to 2000. (*Source*: UNDP, 2000.)

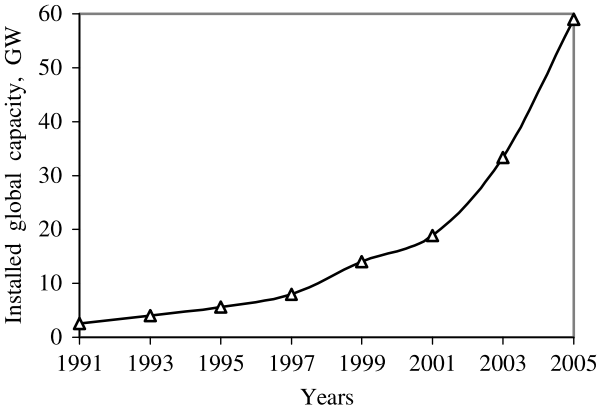

Figure 3. Growth in world wind turbine installed capacity.

Figure 3 shows the growth in world wind turbine installed capacity. Globally, wind power generation has more than quadrupled between 1999 and 2005.

Wind energy is abundant, renewable, widely distributed, clean, and mitigates the greenhouse effect if it is used to replace fossil-fuel-derived electricity. Wind energy has limitations based on geography and meteorology, plus there may be political or environmental problems (e.g., dead birds) with putting turbines in (Garg and Datta, 1998). On the other hand, wind can cause air pollution by degradation and distribution of pieces of pollutants such as waste paper, straw, etc.

Renewable Energy Scenarios

The world developments in the field of energy supply, after the oil crisis of the 70s and the oil crisis of 2004, are showing the way to more serious decisions toward sustainability in strategic energy planning, the improvement of energy efficiency, and the rational use of energy. Renewable energy sources are increasingly becoming a key factor in this line of thought.

Renewable energy is a promising alternative solution because it is clean and environmentally safe. They also produce lower or negligible levels of greenhouse gases and other pollutants when compared with the fossil energy sources they replace. Table 4 shows the global renewable energy scenario by 2040. Approximately half of the global energy supply will come from renewables in 2040 according to European Renewable Energy Council (EREC) (2006). The most significant developments in renewable energy production are observed in photovoltaics (from 0.2 to 784 Mtoe) and wind energy (from 4.7 to 688 Mtoe) between 2001 and 2040.

Biomass is the most used renewable energy source now and in the future. The potential of sustainable large hydro is quite limited to some regions in the world. The potential for small hydro (<10 MW) power is still significant and will be more significant in the future. Wind energy is a technology with annual growth rates of more than 30% during the last years that will become even more significant in the future. Photovoltaics already had impressive annual growth rates of more that 30% during the last years that will become more significant in the future. Geothermal and solar thermal sources will be more important energy systems in the future.

Table 4
Global renewable energy scenario by 2040

	2001	2010	2020	2030	2040
Total consumption (Million ton oil equivalent)	10,038	10,549	11,425	12,352	13,310
Biomass	1,080	1,313	1,791	2,483	3,271
Large hydro	22.7	266	309	341	358
Geothermal	43.2	86	186	333	493
Small hydro	9.5	19	49	106	189
Wind	4.7	44	266	542	688
Solar thermal	4.1	15	66	244	480
Photovoltaic	0.2	2	24	221	784
Solar thermal electricity	0.1	0.4	3	16	68
Marine (tidal/wave/ocean)	0.05	0.1	0.4	3	20
Total renewable energy sources	1,365.5	1,745.5	2,694.4	4,289	6,351
Renewable energy sources contribution (%)	13.6	16.6	23.6	34.7	47.7

Using fossil fuels as the primary energy source has led to serious energy crisis and environmental pollution on a global scale. In order to mitigate environmental problems, renewable energies especially solar energy and wind power, provides cost competitive results. The limitations of solar power are site-specific, intermittent, and thus, not reliable for instantaneous supply. Using batteries to store any energy surplus for later consumption can resolve the time mismatch between energy supply and demand. The shortcomings of battery storage are low-storage capacity, short equipment life, and considerable solid and chemical wastes generated. A system consisting of photovoltaic (PV) panels coupled with electrolyzers is a promising design to produce hydrogen (Ni et al., 2006).

The detailed analysis of the technical, economic, and regulatory issues of wind power is scanned in the European Wind Energy Association (EWEA) Report: "Large scale integration of wind energy in the European power supply: Analysis, issues and recommendations" published in December 2005. In 2005, worldwide capacity of wind-powered generators was 58,982 megawatts; although it currently produces less than 1% of world-wide electricity use, it accounts for 23% of electricity use in Denmark, 4.3% in Germany, and approximately 8% in Spain. Globally, wind power generation more than quadrupled between 1999 and 2005 according to the EWEA (2005).

Figure 4 shows the growth scenarios for global installed wind power (IEA, 2006). In 2004, the International Energy Agency (IEA) Reference Scenario projections for wind energy were updated to 66 GW in 2010, 131 GW in 2020, and 170 GW in 2030. The IEA Reference Scenario projections for wind energy were updated to 75 GW in 2010, 145 GW in 2020, and 202 GW in 2030. The IEA advanced strong growth scenario projected a wind energy market of 82 GW in 2010, 165 GW in 2020, and 250 GW in 2030.

The term biofuel is referred to as liquid or gaseous fuels for the transport sector that are predominantly produced from biomass. Biofuels mainly are bioethanol, biomethanol, biodiesel, biohydrogen, and biogas. There are several reasons for biofuels to be con-

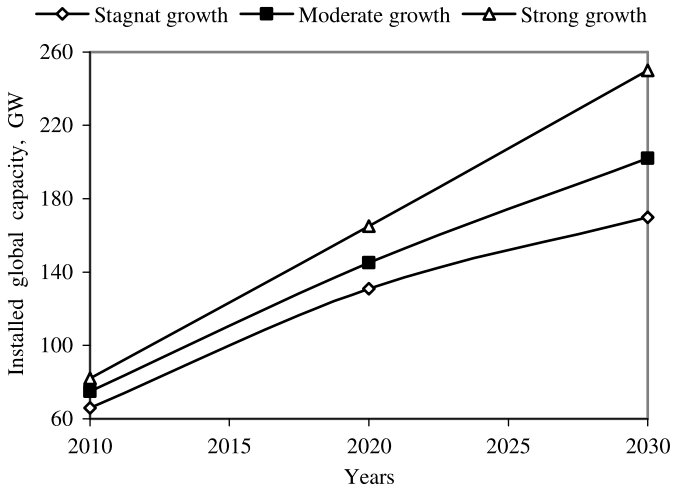

Figure 4. Growth scenarios for global installed wind power. (*Source*: IEA, 2005.)

sidered as relevant technologies by both developing and industrialized countries. They include energy security reasons, environmental concerns, foreign exchange savings, and socioeconomic issues related to the rural sector.

Biofuels are important because they replace petroleum fuels. Biofuels are generally considered as offering many priorities, including sustainability, reduction of greenhouse gas emissions, regional development, social structure and agriculture, and security of supply (Reijnders, 2006).

Biomass provides a number of local environmental gains. Energy forestry crops have a much greater diversity of wildlife and flora than the alternative land use, which is arable or pasture land. In industrialized countries, the main biomass processes utilized in the future are expected to be direct combustion of residues and wastes for electricity generation, bio-ethanol and biodiesel as liquid fuels, and combined heat and power production from energy crops. The future of biomass electricity generation lies in biomass integrated gasification/gas turbine technology, which offers high-energy conversion efficiencies. Biomass will compete favorably with fossil mass for niches in the chemical feedstock industry. Biomass is a renewable, flexible, and adaptable resource. Crops can be grown to satisfy changing end use needs.

In the future, biomass has the potential to provide a cost-effective and sustainable supply of energy, while at the same time aiding countries in meeting their greenhouse gas reduction targets. By the year 2050, it is estimated that 90% of the world population will live in developing countries.

According to International Energy Agency (IEA), scenarios developed for the USA and the EU indicate that near-term targets of up to 6% displacement of petroleum fuels with biofuels appear feasible using conventional biofuels, given available cropland. A 5% displacement of gasoline in the EU requires about 5% of available cropland to produce ethanol while in the USA 8% is required. A 5% displacement of diesel requires 13% of USA cropland, 15% in the EU (IEA, 2006).

The recent commitment by the USA government to increase bio-energy three-fold in 10 years has added impetus to the search for viable biofuels. The advantages of

bio-fuels are the following: (a) bio-fuels are easily available from common biomass sources, (b) they represent a carbon dioxide-cycle in combustion, (c) bio-fuels have a considerable environmentally-friendly potential, (d) there are many benefits for the environment, economy, and consumers in using bio-fuels, and (e) they are biodegradable and contribute to sustainability (IEA, 2004).

The dwindling fossil fuel sources and the increasing dependency of the United States on imported crude oil have led to a major interest in expanding the use of bio-energy. The recent commitment by the United States government to increase bio-energy three-fold in ten years has added impetus to the search for viable biofuels. The EU have also adopted a proposal for a directive on the promotion of the use of bio-fuels with measures ensuring that bio-fuels account for at least 2% of the market for gasoline and diesel sold as transport fuel by the end of 2005, increasing in stages to a minimum of 5.75% by the end of 2010 (Puppan, 2002). Bioethanol is a fuel derived from renewable sources of feedstock; typically plants such as wheat, sugar beet, corn, straw, and wood. Bioethanol is a petrol additive/substitute. Biodiesel is better than diesel fuel in terms of sulfur content, flash point, aromatic content, and biodegradability (Hansen, 2005).

If the biodiesel valorized efficiently at energy purpose, it would be a benefit for the environment and the local population. Job creations, a provision of modern energy carriers to rural communities avoid urban migration and reduction of CO_2 and sulfur levels in the atmosphere. Biofuels include energy security reasons, environmental concerns, foreign exchange savings, and socioeconomic issues related to the rural sector.

Figure 5 shows the shares of alternative fuels compared to the total automotive fuel consumption in the world as a futuristic view (Demirbaş, 2006b). Hydrogen is currently more expensive than conventional energy sources. There are different technologies presently being practiced to produce hydrogen economically from biomass. Biohydrogen technology will play a major role in the future because it can utilize the renewable sources of energy (Nath and Das, 2003).

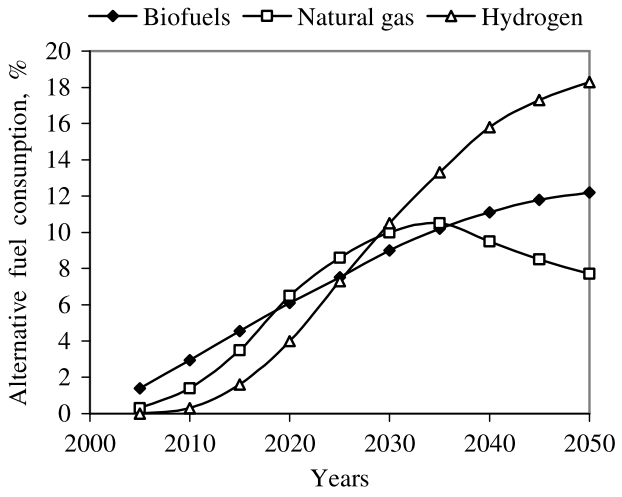

Figure 5. Shares of alternative fuels compared to the total automotive fuel consumption in the world. (*Source*: Demirbaş, 2006b.)

Solar photovoltaic system has been found to be a promising energy source in the future. One of the most significant developments in renewable energy production is observed in photovoltaics (EWEA, 2005; Reijnders, 2006; IEA, 2004).

PV will then be the largest renewable electricity source with a production of 25.1% of global power generation in 2040 (EWEA, 2005). PV systems, or photovoltaics, offer consumers the ability to generate electricity in a clean, quiet, and reliable way. These systems consist of a PV array, control and safety equipment, a battery bank, and usually an inverter. Because the source of light is the sun, they are often called solar cells. Therefore, the photovoltaic process is producing electricity directly from sunlight. PV cells convert sunlight directly into electricity without creating any air or water pollution. PV cells are made of semiconductor material. When light enters the cell, some of the photons from the light are absorbed by the semiconductor atoms, freeing electrons to flow through an external circuit and back into the cell. This flow of electrons is electric current. Solar PV generators are networks of various interconnections between solar cells, diodes, cables, and other components. The efficiency of semiconductor electrodes exposed to concentrated sunlight has been studied and it has been found that the batteries play a vital role in solar photovoltaic refrigeration systems. Despite breakthroughs in operational characteristics of various components of such systems, lead acid batteries continue to be the only viable electrical energy storage devices as of date (Kattakayam and Srinivasan, 2004).

Solar photovoltaic energy is one of the renewable energy sources with the greatest potential worldwide. However, the development of this source of energy depends today on ambitious political supports.

Solar PV and diesel systems should be compared on the basis of life-cycle costs of providing the final services that the customer desires for a number of years (e.g., household lighting, refrigeration, or video). In particular, solar PV and diesel systems should not be compared on the basis of the cost per kilowatt hour of electricity produced under the two systems because such a comparison fails to account for the major operational differences between solar PV and diesel systems. A comparison of solar PV and diesel systems on the basis of life-cycle costs of providing the final services that the customer desires for a number of years shows that the life-cycle costs of solar PV systems are marginally lower than those of diesel systems for households in remote rural areas. Figure 6 shows the configuration of PV system with AC appliances (e.g., household lighting, refrigeration, television, or video).

Conclusion

Photovoltaic (PV) cells, PV systems, or photovoltaics and wind energy will be able to play an important role in the energy scenarios of the future (Masini and Fankl, 2002). The most significant developments in renewable energy production are observed in photovoltaics, wind power, solar thermal, and small hydro energy production.

If only electricity supply was assumed for the years up to 2040, the contribution of renewable energies in this field is much higher compared to total energy supply in 2040 (EWEA, 2005). The electricity generation from renewables will be more than 80% to the total global electricity supply in 2040. According to current scenarios, PV will then be the largest renewable electricity source with a production of 25.1% of global power generation followed by wind and biomass in 2040.

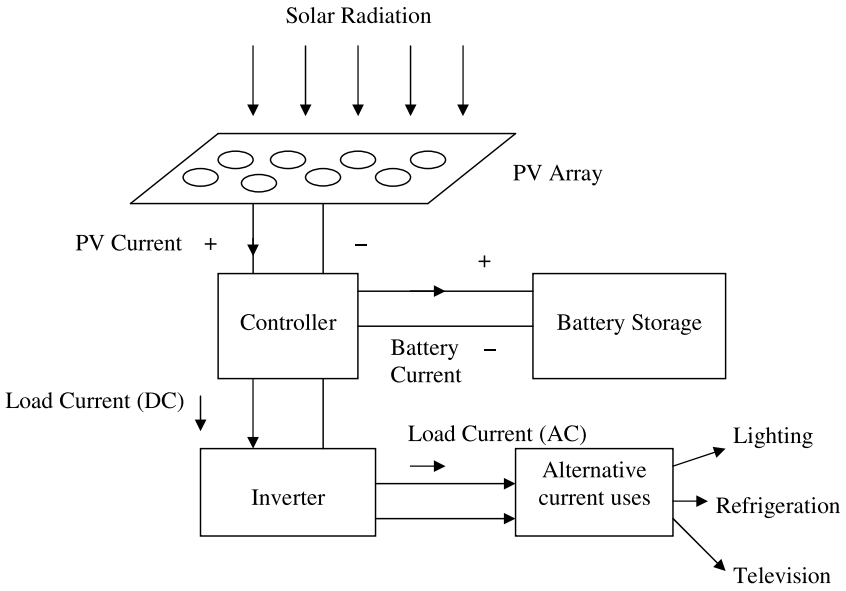

Figure 6. Configuration of PV system with AC appliances.

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