CHAPTER 1

INTRODUCTION

In 1973, mankind witnessed its first shock in the form of oil crisis after World War – II. In 2007, when the crude oil price crossed 100 USD, the entire world turned its attention to alternative, renewable and eco-friendly energy technologies. The Noble Prize for peace had been announced in 2007 for persons who worked for highlighting the impact of “Global Warming”. It has made the world population to think about the ill-effects of present levels of emissions of carbon based energy sources and the need for environmental friendly alternative. This chapter briefly presents the energy demand, supply and need for eco-friendly renewable sources. The role of solar thermal sources, in general, focuses on the need for carrying out many studies of which the present research is one.

1.1 WORLD ENERGY SCENARIO

The issue on security of supply is now at the top of the energy policy agenda. Concern is focused both on price security and security of physical supply. At present around 80% of global energy demand is met by fossil fuels. The unrelenting increase in energy demand is matched by the finite nature of these sources. The regional distribution of oil and gas resources also does not match the distribution of demand. Some countries have to rely almost entirely on fossil fuel imports. Table 1.1 shows the world fossil fuel reserves.
**Coal:** Coal was the world’s largest source of primary energy until it was overtaken by oil in 1960s. Today, coal supplies almost one quarter of the world’s energy. Despite being the most abundant of fossil fuels, coal’s development is currently threatened by environmental concerns; hence its future will unfold in the context of both energy security and global warming.

Coal is abundant and more equally distributed throughout the world than oil and gas. Global recoverable reserves are the largest for fossil fuels and most countries have at least some. Moreover, existing and prospective big energy consumers like the US, China and India are self-sufficient in coal and will be so in the foreseeable future. Coal has been exploited on a large scale for two centuries, so both the product and the available resources are well known; no substantial new deposits are expected to be discovered. Extrapolating the demand forecast, the world will consume 20% of its current reserves by 2030 and 40% by 2050. Hence, if current trends are maintained, coal would still last several 100 years.

**Oil:** Oil is the blood of modern global economy, as the effects of supply disruptions of 1970s made it clear. It is the number one source of energy, providing 36% of the world’s needs and the fuel is employed almost exclusively for essential uses such as transportation. However, a passionate debate has developed over the ability of supply to meet increasing consumption needs, a debate obscured by poor information and stirred by recent soaring prices.

**Gas:** Natural gas has been the fastest growing fossil energy source in the last two decades, boosted by its increasing share in the electricity generation mix. Gas is generally regarded as a largely abundant resource and public concerns about depletion are limited to oil, even though a few in-depth studies address
the subject. Gas resources are more concentrated than oil so they were discovered faster because a few massive fields make up for most of the reserves. The largest gas field in the world holds 15% of the “Ultimate Recoverable Resources” (URR), compared to 6% for oil. Unfortunately, information about gas resources suffers from the same bad practices as oil data because gas mostly comes from the same geological formations and the same stakeholders are involved.

Most reserves are initially understated and then gradually revised upwards, giving an optimistic impression of growth. By contrast, Russia’s reserves, the largest in the world, are considered to have been over-estimated by about 30%. Owing to geological similarities, gas follows the same depletion dynamic as oil and thus the same discovery and production cycles. In fact, existing data for gas is of worse quality than for oil and some ambiguities arise as to the amount of gas already produced because flared and vented gas is not always accounted for. As opposed to published reserves, the technical ones have been almost constant since 1980 because discoveries have roughly matched production.

**Nuclear:** Uranium, the fuel used in nuclear power plants, is a finite resource whose economically available resource is limited. Its distribution is almost as concentrated as oil and does not match regional consumption. Five countries - Canada, Australia, Kazakhstan, Russia and Niger - control three quarters of the world’s supply. As a significant user of uranium, however, Russia’s reserves will be exhausted within ten years. Secondary sources, such as old deposits, currently make up nearly half of worldwide uranium reserves. However, those sources will soon be used up. Mining capacities will have to be nearly doubled in the next few years to meet current needs.
A joint report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency, (Uranium 2003: Resources, Production and Demand) estimates that all existing nuclear power plants will have used up their nuclear fuel, employing current technology in less than 70 years. In the light of various scenarios for the worldwide development of nuclear power, it is likely that uranium supplies will be exhausted sometime between 2026 and 2070. Assuming a downward trend in the use of nuclear power, realistic estimates indicate that supplies will be enough for only a few countries by 2050. This forecast includes uranium deposits as well as the use of Mixed Oxide Fuel (MOX), a mixture of uranium and plutonium.

The reserves chaos: Public data about oil and gas reserves are strikingly inconsistent and potentially unreliable for legal, commercial, historical and sometimes political reasons. The most widely available and quoted figures, those from the industry journals Oil and Gas Journal and World Oil have limited value as they report the reserve figures provided by companies and Governments without analysis or verification. Moreover, as there is no agreed definition of reserves or standard reporting practice, these figures usually stand for different physical and conceptual magnitudes. Confusing terminology (‘proved’, ‘probable’, ‘possible’, ‘recoverable’, ‘reasonable certainty’) only adds to the problem.
Table 1.1 Overview of fossil fuel reserves and resources scenario

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<td>Gas Reserve</td>
<td>6,600</td>
<td>6,200</td>
<td>C 5,400</td>
<td>C 5,900</td>
<td>C 5,500</td>
<td>C 5,300</td>
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<td>Gas Resources</td>
<td>9,400</td>
<td>11,100</td>
<td>NC 8,000</td>
<td>NC 8,000</td>
<td>NC 9,400</td>
<td>NC 100</td>
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<td>Additional occurrences</td>
<td>10,800</td>
<td>10,800</td>
<td>NC 10,800</td>
<td>NC 10,800</td>
<td>NC 23,800</td>
<td>NC 111,900</td>
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<td>5,700</td>
<td>C 5,900</td>
<td>C 6,300</td>
<td>C 6,000</td>
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<td>Oil Resources</td>
<td>10,200</td>
<td>13,400</td>
<td>NC 6,600</td>
<td>NC 8,100</td>
<td>NC 5,100</td>
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<tr>
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<td>13,900</td>
<td>NC 15,500</td>
<td>NC 13,900</td>
<td>NC 15,200</td>
<td>NC 25,200</td>
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<td>Coal Reserve</td>
<td>23,600</td>
<td>22,500</td>
<td>42,000</td>
<td>25,400</td>
<td>20,700</td>
<td>16,300</td>
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<td>Coal Resources</td>
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<td>165,000</td>
<td>100,000</td>
<td>117,000</td>
<td>179,000</td>
<td>179,000</td>
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<tr>
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<td>125,600</td>
<td>121,000</td>
<td>125,600</td>
<td>121,000</td>
<td>121,000</td>
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<td>Total Resource (reserves + resources)</td>
<td>180,600</td>
<td>223,900</td>
<td>212,200</td>
<td>213,200</td>
<td>281,900</td>
<td>361,500</td>
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<td>Total Occurrence</td>
<td>1,204,200</td>
<td>1,218,000</td>
<td>1,218,000</td>
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<td>1,218,000</td>
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Reserves, resources and additional occurrences of fossil energy carriers according to different authors. C: conventional (petroleum with a certain density, free natural gas, petroleum gas, NC: non-conventional) heavy fuel oil, very heavy oils, tar sands and oil shale, Gas in coal seams, aquifer gas, natural gas in tight formations, gas hydrates). The presence of additional occurrences is assumed. Based on geological conditions, but their potential for economic recovery is currently very uncertain. In comparison: in 1998, the global primary energy demand was 402 EJ (UNDP et al 2000).
Historically, private oil companies consistently underestimated their reserves to comply with conservative stock exchange rules and through natural commercial caution. Whenever a discovery was made, only a portion of the geologist’s estimate of recoverable resources was reported; subsequent revisions would then increase the reserves from that same oil field over a period of time. National oil companies, almost fully represented by Organization of Petroleum Exporting Countries (OPEC), are not subjected to any sort of accountability and so their reporting practices are even less clear. In the late 1980s, OPEC countries blatantly overstated their reserves while competing for production quotas, which were allocated as a proportion of the reserves. Although some revision was needed after the companies were nationalized, between 1985 and 1990, OPEC countries increased their joint reserves by 82%. Not only were these dubious revisions never corrected, but many of these countries have reported untouched reserves for years, even if no sizeable discoveries were made and production continued at the same pace. Additionally, the former Soviet Union’s oil and gas reserves have been overestimated by about 30% because the original assessments were later misinterpreted.

Whilst private companies are now becoming more realistic about the extent of their resources, the OPEC countries hold the majority of reported reserves and information on their resources is as unsatisfactory as ever. In brief, these information sources should be treated with considerable caution. To fairly estimate the world’s oil resources a regional assessment of the mean backdated (i.e. ‘technical’) discoveries would need to be performed
1.2 GROWTH OF PRIMARY ENERGY USE IN INDIA

Being a growing economy, both India and China will use more primary energy as shown in Figure 1.1. India and China will consume about 45% of total world energy use, about 80% of world coal, 40% of world oil, 60% of world nuclear and nearly 40% of world hydro-energy use if the current energy technologies are planned. This will lead to very large CO₂ emissions and other environmental consequences. The world as well as the India has to focus more on alternate energy scenarios.

According to the U.S. Energy Information Administration (EIA), coal accounts for nearly 41% of India’s total energy consumption, followed by nearly 23% for solid biomass and waste as shown in Figure 1.2. Petroleum accounts for nearly 23% of total energy consumption, natural gas 8%, nuclear and other renewable sources nearly 5%. Although nuclear power comprises a very small percentage of total energy consumption at this time, it is expected to increase in light of international civil nuclear energy cooperation deals. According to the Indian Government statistics, nearly 30% of India’s total energy needs are met through imports.
Figure 1.1 Increase in primary energy demand and investment between 2005 and 2030
(Source: World Energy Outlook (2007))
Figure 1.2 Total energy consumption in India (2011)

1.3 NEED FOR ALTERNATE ENERGY USE STRATEGIES

There is an imperative need to sustain growth. At the same time, the use of carbon based fuels must be kept minimum. Such aspects are claimed to be possible, if the following five strategies are implemented.

(i) Implementing clean, renewable solutions and decentralizing energy systems: There is no energy shortage. All human beings need to do is to use existing technologies to harness energy effectively and efficiently. Renewable energy and energy efficiency measures are ready, viable and increasingly competitive. Wind, solar and other renewable energy technologies have experienced double digit market growth for the past decade. Just as climate change is real, so is the renewable energy sector. Sustainable decentralized energy systems produce less carbon emissions, are cheaper and involve less dependence on imported fuel. They create more jobs and empower local communities. Decentralized systems are more secure and more efficient. This is what the energy revolution must aim to create.

(ii) Respecting natural limits: Human beings must learn to respect natural limits. There is only so much carbon that the atmosphere can absorb. Each year, the world emits about 23 billion tons of CO₂; industrial and human activities are literally filling up the sky. Geological resources of coal could provide several 100 years of fuel, but the world cannot burn them and keep within safe limits. Oil and coal development must be ended. To stop the earth’s climate spinning out of control, most of the world’s fossil fuel reserves – coal, oil and gas – must remain in the ground. The goal is for humans to live within the natural limits of our small planet.
(iii) Phasing out dirty, unsustainable energy: The world needs to phase out coal and nuclear power. Human beings cannot continue to build coal plants at a time when emissions pose a real and present danger to both ecosystems and people. And human beings cannot continue to fuel the myriad nuclear threats by pretending nuclear power can in any way help to combat climate change. There is no role for nuclear power in the energy revolution.

(iv) Equity and fairness: As long as there are natural limits, there needs to be a fair distribution of benefits and costs within societies, between nations and between the present and future generations. At one extreme, a third of the world’s population has no access to electricity, whilst the most industrialized countries consume much more than their fair share. The effects of climate change on the poorest communities are exacerbated by massive global energy inequality. If human beings are to address climate change, one of the principles must be equity and fairness, so that the benefits of energy services - such as light, heat, power and transport - are available for all: north and south, rich and poor. Only in this way, human beings can create true energy security, as well as the conditions for genuine human security.

(v) Decoupling growth from fossil fuel use: Starting in the developed countries, economic growth must fully decouple from fossil fuels. It is a fallacy to suggest that economic growth must be predicated on their increased combustion. The human beings need to use the energy the world produce much more efficiently. We need to make the transition to renewable energy – away from fossil fuels – quickly in order to enable clean and sustainable growth. It is estimated if the above said five principles are effectively implemented, the share of the non-renewable sources can be reduced by 50% from the 2003 levels as shown in Figure 1.3.
Figure 1.3 Development of primary energy consumption under the energy evolution scenario

(‘Efficiency’ = Reduction compared to the projected scenario by energy conservation measures and energy efficient technologies - Source: www.energyblueprint.info)
1.4 SOLAR ENERGY USE AND SOLAR HOT WATER SYSTEMS

Solar energy is a very large inexhaustible source of energy. The power from the sun intercepted by the earth is approximately $1.8 \times 10^{11}$ MW, which is many thousand of times larger than the present consumption rate on the earth or all commercial energy sources. Solar energy could supply all the present and future energy needs of the world on a continuous basis. This makes it one of the most promising non-conventional energy sources. Solar energy has two factors in its favour. Firstly, unlike fossil fuel and nuclear power, it is an environmentally clean source of energy. Secondly, it is free and available in adequate quantities in almost all parts of the world where people live. Among various solar energy options, solar hot water systems have attained the commercial stage. On the other hand, it is a dilute source of energy. Even in the hottest regions of the earth, the solar radiation flux available rarely exceeds 1 kWh/m$^2$ and the total radiation over a day is about 7 kWh/m$^2$. It leads to the requirement of large collecting areas in many applications and hence results in excessive cost. One more problem associated with solar energy is that the availability varies widely with time. Consequently, the energy collected when sun is shining must be stored for use during periods when it is not available.

Solar energy can be utilized in any one form either as direct or indirect method. Thermal and photovoltaic are direct methods. Water power, wind, biomass, wave energy, ocean temperature differences and marine current are indirect methods. Solar energy is directly utilized with the help of solar collectors by direct method. Hot water production, cooking, space heating etc. are some of the applications of solar energy. According to Solangi et al (2011), solar PV installations across the world are providing
14 GW of photovoltaic electricity as on 2010, which is expected to grow rapidly in the future.

Solar water heating is one of the prime attractive solar thermal energy applications from an economic standpoint. In India, a large number of systems with flat-plate collectors have been installed. The solar water heating systems are utilized for domestic purposes or for meeting the needs of industries or commercial establishments. Solar water heating systems are classified as natural circulation (thermosyphon) systems, forced circulation systems and wind assisted circulation systems.

The essential components of the natural circulation solar water heating system are flat plate collector and storage tank. Water flowing through the collector panel is heated by solar energy and it flows to the top of the water tank by natural circulation and is replaced by the cold water from the bottom of the tank. By natural circulation, solar hot water system is suitable for domestic purpose when the requirement of hot water is low but is not sufficient when the requirement is large. Water from a storage tank is pumped through a collector, where it is heated and then flows back to the storage tank.

Both natural and forced circulation systems are widely used. Natural circulation systems involve thermosyphon flow (by natural circulation) whereas the forced circulation systems use the pump for the circulation of water. The flow rate of water across the collector panel is lower for thermosyphon flow when compared with that for forced circulation. Thus, the forced circulation systems are more efficient than natural circulation systems. However, the pump in the forced circulation system uses electricity, mostly generated by using carbon based fuels. According to GSR-2011, India has been ranked third in the world annual capacity additions and fifth in terms of total wind energy installed capacity. In order to compensate the electricity
losses of about 24.7% during 2010-11, a cheaper, non-polluting and environment friendly solution to power rural India is one of the essential needs of the day. The windmill driven pump uses 100% renewable wind energy and is eco-friendly. This enhances the performance of the existing natural circulation system to the level of forced circulation type. A novel idea of filling CO\textsubscript{2} in the collector panel is implemented for the natural, forced and windmill assisted circulation systems.

Based on the concept of green house effect, it was intended to observe the role of CO\textsubscript{2} gas in improving the efficiency of all three types of solar hot water systems. In this study, experiments were conducted to analyse and compare the performance of natural, forced and windmill assisted pump driven circulation systems with and without CO\textsubscript{2} filled in the collector panel.

1.5 OUTLINE OF THE THESIS

The review of various works carried out related to Solar Hot Water System (SHWS), various performance enhancement techniques and system optimization are briefly presented in Chapter 2. Chapter 3 explains the details of experimental facility used to assess the performance of Natural Circulation System (NCS), Forced Circulation System (FCS) and Windmill Assisted Circulation System (WACS) with and without CO\textsubscript{2} filled in the collector panel. Next, the data and results are presented and discussed in Chapters 4, 5 and 6 respectively. Chapter 7 provides the comparison among the six modes and Chapter 8 lists the major conclusions and scope for future work. The experimental data of various modes of operation and uncertainty analysis are presented in Appendices, followed by a list of references.