CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

1.1.1 An Overview of Global Energy Scenario

Primary supply of clean and sustainable energy is one of the top global issues. A greater portion of today's energy demand (>85%) is fulfilled by fossil fuel based resources but at the expense of the global warming and consequent severe impact on climate changes (IEA, 2013). The statistics of increasing energy demand and depleting fossil fuels are alarming: (i) the energy demand is expected to increase 2 folds by 2050; and (ii) due to depleting fossil fuel reserves an additional energy demand equal to today's total energy consumption is expected in next three decades (Grätzel, M., 2009 and Perez et al., 2011). The renewable energy resources such as solar and wind which are cost effective and abundant in nature are fairly distributed across the globe; and therefore, have potential to contribute towards this energy gap (Nelson J., 2013). These resources also eliminate the environment issues associated with the use of fossil fuels. Among the renewable energy resources, solar energy alone has a potential to meet world's primary energy demand; it requires covering less than 0.4% of our planet's surface with 15% efficient solar panels (Docampo et al., 2014). Alternatively, using 25% efficient solar panels, a solar farm of area ~400 km × 400 km in the Sahara desert would meet the projected energy demand. Above all, energy from sunlight is 200 times more abundant than all other renewable energy resources combined (Perez, et al., 2011).

1.1.2 Emergence of Photovoltaic Technology

Photovoltaic effect was discovered in the 19th century by Edmond Becquerel. Subsequently, solar energy appears not only as a promising alternative energy resource but also a better off–grid choice in remote applications and in portable electronics. The solar cell technology is divided into three types, (i) crystalline silicon solar cells, (ii) thin film solar cells ($CuInGaSe_2$, CdTe etc.), as their working electrodes comprise much thinner film (typically ~1 μm thick) compared to first generation, and (iii) molecular absorber solar cells in which molecules or inorganic clusters are the primary absorbers. Examples of the last type are polymer solar cells, dye-sensitized solar cells (DSCs), quantum dot solar cells, and recently emerged perovskite solar cells. Over half a century research in silicon based solar cells, which currently dominate the photovoltaic market, resulted in an installed capacity of greater than 40 GW till date, up from 1.5 GW in 2000 as shown in Figure 1.1 (British Petroleum, 2013).

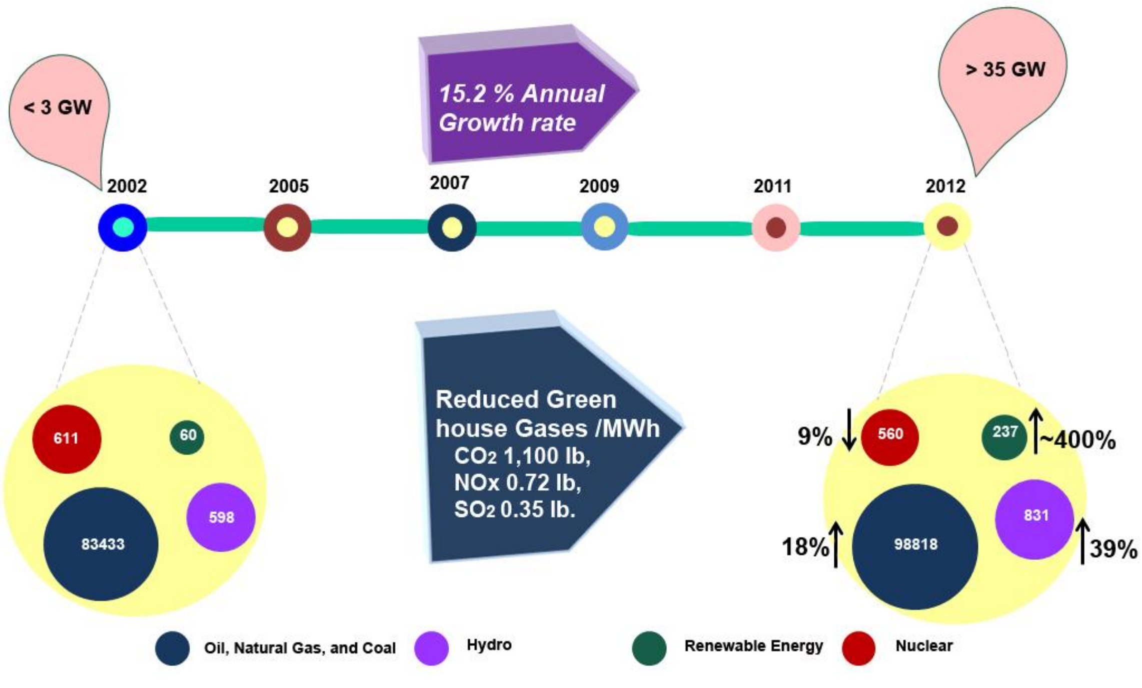

Figure 1.1: A chart showing paradigm shift of the share of renewable energy resources. The values are in million tons of oil equivalents (mtoe).

Source: Fakharuddin A. et al. 2014d

These installations brought solar cells (mostly silicon based) to contribute to energy demand in peak hours; in Germany ~5.3% of daily demand is fulfilled by solar electricity which increases to 20% in longer sunny days (Nelson J., 2013; Wirth, 2013). Commercial modules of silicon solar cells (first generation) of efficiency (η) ~20% are available in the market. On the other hand, thin film solar cells (second generation) based on $CuInGaSe_2$ (CIGS) have achieved η>20% at laboratory scale (ZSW, 2013; NERL, 2014); and modules of η ~15% are commercially available (First Solar, 2013). Despite the rapidly increasing global installations, these solar cells (first and second generation) still suffer from critical issues such as longer payback time (2 – 4 years), high cost associated with extreme purity requirement of the active material, scarcity of materials such as indium and silver, and their low working capability in cloudy hours or in shaded region (Hardin et al., 2012 and Nelson J., 2013). These drawbacks bring into account the third generation photovoltaics, resolving most of the issues of the first two generations. However, the third generation devices currently suffer from lower photoconversion efficiency (η) than the other two.

1.1.3 Molecular absorber solar cells

In general, a solar cell absorbs solar irradiations using a semiconducting material and converts it into electrical energy by splitting up an electron–hole pair (exciton) during absorption. The exciton is separated into mobile carriers at the p–n junctions in silicon solar cells; the charges thereby produced are required to travel ~300 μm thick photoanode layer. A complete collection of photogenerated electron from such thick layer puts stringent conditions on purity of the materials. The second generation solar cells are although few microns thick, their vacuum based fabrication to improve the crystallization of $CuIn_xGa_{1-x}Se_2$ (CIGS) films increase the cost of device fabrication. The molecular absorber solar cells offer remedy to such undesirable fabrication cost; they typically do not require a clean room for fabrication and are often compatible with roll–to–roll industrial production. Among various third generation solar cells, the dye sensitized solar cells (DSCs) are promising as they are light weight, transparent and can be made on flexible substrates. Due to their significantly shorter film thickness (~15 μm), they do not need high quality semiconductors as the photogenerated electrons