1
Introduction

"Perhaps the largest challenge for our global society is to find ways to replace the slowly but inevitably vanishing fossil fuel supplies by renewable resources and, at the same time, avoid negative effects from the current energy system on climate, environment, and health."

- Michael Graetzel [Grätzel, 2009]

1.1 MOTIVATION

Solar energy is the basis of life. For many millennia, the habitat of planet relied solely on solar energy, humanity survives against nature by indirect and direct renewable forms like lighting, heat and biomass respectively. Today with the growing population, energy demand is mainly fulfilled by fossil non-renewable resources like natural gas, petroleum and coal as well as on nuclear power. The fossil non-renewable resources have been developed from geological transformation of organic materials over millions of years. Our dependence on the fossil resources causes geopolitical tensions due to its limited quantity and environmental damage by the emission of carbon dioxide which puts our climate at stake due to climatic changes and greenhouse effects. The nuclear power comes with the problem of generation and storage of high level radioactive waste. The safety of nuclear power plant is also a major concern. It is crystal clear and necessary to move toward methods with renewable, sustainable and low environmental impact, and well quoted by Micheal Gratzel [Grätzel, 2009].

In the modern world, with new technological advancements and economy, more energy is being required to continue the development and rising demand due to the increase in world population. The world primary energy demand is estimated to be increased to 25.8 TW by 2035. The annual primary energy consumption is appraised by 1.6% per year.

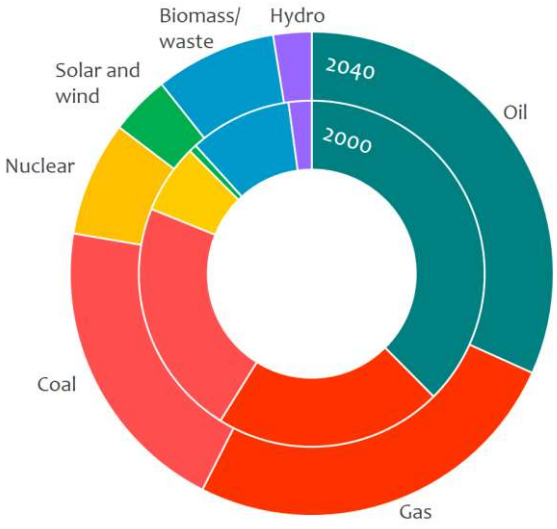

Figure 1.1 : World energy demand by energy source

The Figure 1.1 illustrate the world energy demand from 2000 to 2040 (prediction). It can be seen from the graph that fossil non-renewable resources and nuclear power will continue to control the market (can easily notify that coal and other sources are predicted to decrease their demand in further years), but the drastic increment in renewable energy demand is estimated by 2040. Over the period renewable energy is the world's fastest growing demand by an average 2.6% per year.

All the energy sources, non-renewable and renewable resources will be needed to contribute to meet this rising global energy demands by 2040 (see Figure 1.2a). Oil will be expected to decline its share as a direct source but will be in the mainstream in the other form. Now, coal is the largest energy source and it will remain as a global demand source till 2025 and then its consumption is predicted to decline. The advancement in technology towards energy efficiency and to curb CO_2 emission together will shift to other energy sources [EIA, 2016].

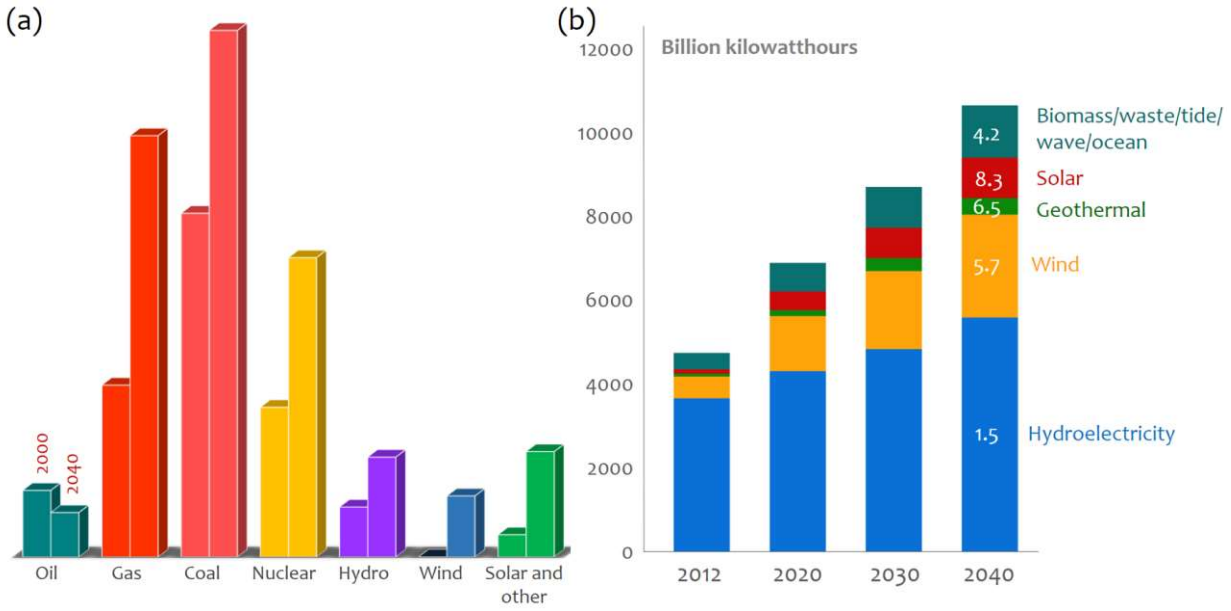

Figure 1.2 : (a) Power generation by various energy source and (b) Growth of renewable energy sources from 2012 to 2040

The World will be emphasizing more on cleaner fuels like natural gas, these sources are expected to fulfill of about one-fifth of total demand. Natural gas is projected to fulfill 40 % of the world's energy demands by 2040, where total rise will be above 50%. Nuclear energy sees strong gain over the period and will be the main source of energy as non-CO_2 emitting energy source. Renewable energy sources like hydro, wind and biofuels will also predict grow rapidly and will be raising their share by 2.9% per year in global total energy generation. The implementation of the same share is predicted to increase from 22 to 29% in 2012-2040. With the net growing rate of 8.3% per year, solar energy will emerge as a fastest rising form of renewable energy as shown in Figure 1.2b. Over time, 5.9 trillion kilowatt hours of renewable energy will be generated. Solar energy will be predicated to harvest 859 billion kilowatt hours and it shares about 15% of total global energy [EIA, 2016].

The best way to harvest and produce electricity from sunlight is to utilize photovoltaic cells (PV). Very good reason for this, 1.7×10^5 TW per year of solar energy strikes on earth surface which is 1×10^4 times larger than our need. For decades, solar photovoltaics were considered only for certain signaling and communication in a remote area and for space applications. Now this trend is changing over the past years due to the new policies, enthusiasm towards renewable energy and most important technology development lowered the prize of solar cell with high efficiency. During the past few years, cost per watt has fallen significantly. To compete with other electricity sources, PV electricity still has more to drop. New technology innovation opens a new era (third generation of solar cells) and shows good

potential to replace conventional Si-based solar cells. The dye sensitized solar cells (DSSC) has been firstly introduced by O'Regan and Gratzel in 1991 [O'Regan and Gratzel, 1991]. The DSSC holds potential for cost effective and simple manufacturing, with flexible substrates they seem to be more viable for commercial application. This technology is in its development stage. In conventional solar cells, highly pure raw material and harmful chemicals were used. Instead of, DSSC mainly consists of wide band semiconductor metal oxides which are very abundant and environmental friendly. The metal oxide is the key junction between upcoming technology such as perovskite solar cells and DSSC. Addressing issues like surface area, defect density, charge transport, optimizing morphology and phase of these metal might be more advantageous, and will help to harvest more light. This will be a small and indirect step towards achieving 859 billion kilowatt hours or more by 2040.

These metal oxides can be explored for removal of organic and metal impurities from the water. The main contaminants, dye, organic industrial waste and very hazardous metals like chromium can be easily arrested by simple process like photodegradation. Such frontier applications of these metals oxides, make them more considerable material in the research.

1.2 OBJECTIVES AND SCOPES

The present work is aimed at developing metal oxide with new physical properties to enhance its application in DSSC and water treatment as shown in Figure 1.3. Major efforts have been made to develop a simple one step, sub-zero temperature method to synthesize well crystallized mixed phase nanoparticles with controlled size and shape. Within this framework, synergetic effect between the phase composition and variation in shape and size of metal oxide nanoparticles at sub-zero temperature is revealed. In order to provide more electron trapping sites and separate the electrons and holes, a novel heterojunction solid nanospheres made up of metal oxides have been explored by an environmental friendly and facile route. These mesoporous structures have been comprised of polydisperse aggregates of both oxides and possess type-II heterojunction. Further to enhance light scattering, metal nanodots with dielectric spacer nature has been examined. The hydrogenation has been performed and correlated with lowering the band gap with shift in the optical absorption towards visible region.

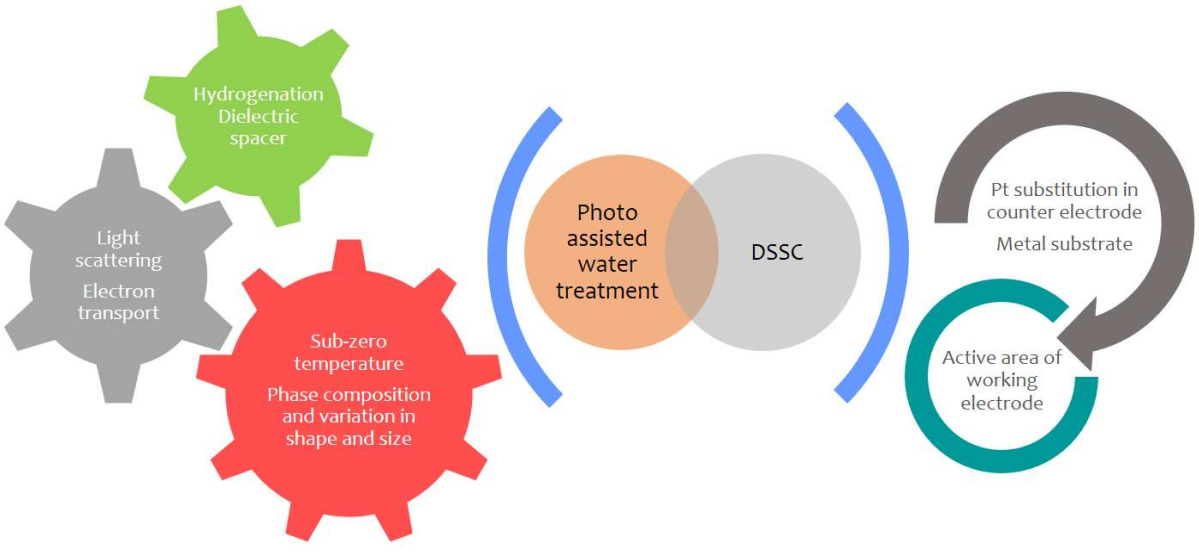

Figure 1.3 : Schematic illustration of the developing metal oxide with new properties to enhance its application in various fields.

The good electrode material is a necessity to bring about best performing devices. Thus, the materials synthesized are incorporated as an electrode material for fabrication of DSSC

devices. Due to the variation in synthesis temperature and other different conditions, the synthesized materials showed different morphology with distinct phases has been appointed as photoanode material. The materials with spherical morphologies provide good light scattering property and entrapment of the incoming photons. Moreover, this structure supports more sites for dye attachment facilitating good dye absorption which will eventually lead to high performing DSSC. The photoanode material showed deep charge trapping sites inconsistent with the literature which acts as good solar absorbing materials. Overall, the material synthesized has proven as a better performing photoanode than the commercially available ones with increased current density and efficiency. Furthermore, use of graphene as a counter electrode material have been exploited and tried with the synthesized materials as photoanode material. With the use of these metal oxides, this will open a window towards upcoming technology like perovskite solar cells. Also, photo-assisted water treatment by use of the synthesized material as catalysis is another application, where water impurities like hazardous chromium and organic dye have been removed.