CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Energy consumption would increase in the coming years due to growing economies and increasing population. Primary supply of sustainable and clean energy is one of the major challenges of the 21st century. A recent report by British Petroleum points that 1.3 billion more people will become new energy consumers by 2030 with a total population of 8.3 billion (British Petroleum, 2013). Exxon’s 2040 Energy Outlook projects 35% increase in global electricity demand during 2010–2040 (Exxon Mobil, 2014). Developing non-OECD countries alone will experience a 150% increase in electricity demand lead by India and China (Exxon Mobil, 2014). By the present energy growth of 1.6% per year, 35 years are required to have such magnitude of energy; therefore, a crisis is inevitable (U.S. Energy Information Administration, 2013). This increased energy demand is one part of the scenario; the other part is depleting natural resources, increased production cost, high environmental concerns such as global warming due to excessive use of fossil fuels. Over 85% of the primary supply in the present-day energy mix is contributed by the fossil fuels – the main contributor to the global warming; thereby putting the life sustenance in the planet at an increased risk. All these concerns point out to turn our attention to clean, sustainable, and zero cost sources of energy such as wind, solar, tides, etc.

Sustainable energy is a dual topic of energy conversion and storage. Energy is converted into electricity when the renewable resources are available and stored until it is utilized. Secondary lithium ion batteries (LIBs) and supercapacitors (SCs) have become two popular protocols for energy storage devices because they are rechargeable,
could be produced in diverse design with light weight and flexibility, and are easy to manufacture (Chen et al., 2009). The rate of charging or discharging of energy per unit mass is defined as power density and the total energy stored per unit mass is the energy density (Burke, 2000). The LIBs provide the highest energy density (150 – 200 Wh/kg) but at the expense of cycle life (<10^3 cycles) and power density (0.5 – 1 kW/kg); whereas SCs have higher power density (2 – 5 kW/kg) and longer cycle life (10^4–10^6 cycles) but suffer from inferior energy density (>5 Wh/kg) (Kotz and Carlen, 2000). Nevertheless, SCs are the devices of choice when high power applications are sought.

The comparison of energy storage and power capabilities of a storage device is represented by Ragone plot. Figure 1.1 is a general Ragone plot of energy storage devices including capacitors, SCs, and batteries. Batteries and fuel cells were typical low power density devices whereas conventional capacitors may have high power density of >10^6 W/kg at very low energy density, <0.1 Wh/kg. One would see that the SCs fill the large gap between conventional capacitors and batteries. Still SCs suffer from energy storability when the power capability is increased. Therefore, development of electrode materials of SCs gained tremendous attention to simultaneously provide high energy and power densities which are unavailable in other class of energy storage devices.

The SCs are divided into two categories; viz. electrochemical double layer capacitors (EDLCs) and pseudocapacitors (PCs) which are distinguished by their charge storage mechanism (Shen et al., 2012). The EDLCs arise from the charge accumulation in an electrochemical-double layer formed at the interface between the charged surface of an electrode-electrolyte system (non-faradaic) (Conway, 1999). Meanwhile, PCs undergo faradaic reaction through an electron transfer process that produces a change in chemical or oxidation state in the electroactive material during charge storage process (Conway, 1999 and Shen et al., 2012). Because of the non-faradaic process, EDLCs could be charged and discharged at a faster rate; therefore have high power density. However, they have inferior energy densities. The PCs are in other way around – they have superior energy density but a compromised power density. Beneficial advantages both EDLCs and PCs are combined in asymmetric capacitors in which anode is fabricated using a pseudocapacitor material and cathode using an EDLC material (Ma et
al., 2007 and Liu et al., 2006). There are also materials developed which encloses PC and EDLC combining in a single materials systems, called hybrid materials (Aziz et al., 2013).

![Figure 1.1: Ragone plot for various energy storage and conversion devices.](image)


EDLCs use carbons, which are occurring in various allotropes including graphite, graphene, diamond, nanotubes, fullerene, amorphous carbon, and glassy carbon (Walker, 1972). Activated carbons (ACs) are amorphous and highly porous that offer high surface to volume ratio; and therefore, a popular choice as an electrode material for EDLCs. ACs satisfies basic requirement of electrode material due its high electric conductivity, low cost, large surface area, and porosity (Su and Centi, 2013). There is a new approach in production of ACs by utilizing biomass materials from agricultural and industrial sector byproducts (Wei and Yushin, 2012) such as ginkgo shells (Jiang et al., 2013), celtuce leaves (Wang et al., 2012), banana fibers (Subramanian et al., 2007), argan seed shells (Elmouwahidi et al., 2012), coffee shells (Jisha et al., 2009), and so on. A summary of this sources are given in the next chapter.