# CEN 4481 Carbon Materials for Energy Storage and Conversion Systems

## Introduction

Since the beginning of this millennium, our world has changed dramatically. Many of the most dire predictions about fuel supply and environmental impact forecasted a generation ago are beginning to come true much more quickly than we thought possible. While many of us grew up with the misguided belief that oil and coal are endless feedstock, we now know that if the supply is not dwindling, it will soon become more expensive to exploit. While we debated over the validity of greenhouse concerns, the problem has now become far too large to ignore.

Climatic perturbations such as hurricanes, tsunamis, melting icebergs, and incredibly hot summers have become common in most regions of the world. At the same time, the price of oil has started to increase due to industrialization in emergent countries. These two developments have led politicians to realize the importance of limiting oil consumption. In most developed countries, several programs have been launched for better energy consumption such as limiting the energy spoiling, improving the energy efficiency of systems (e.g., domestic heating/cooling, powering of transportation systems, and industrial uses) and changing citizens' behaviour with regard to energy consumption and environment protection.

There is certainly a general agreement that electricity and hydrogen represent cleaner energy carriers than oil or coal, provided that the latter are not used for their production. Nuclear and renewable energies should progressively assume a larger role for electricity production. However, because of the uncontrolled nature of their production, renewable energies are far from ideal and they require storage systems to regulate their production and consumption. Similarly, although seemingly attractive, powering an electric vehicle is not an

easy task, as many criteria such as cost, volume, and weight of systems have to be taken into account. Powering an electric vehicle requires onboard delivery either either from a rechargeable battery or from a fuel cell fed by a hydrogen reservoir. High-performance energy storage and conversion systems must be developed to meet the growing inductrial and societal demans. In this domain, materials and particularly carbons play a major role. Research and industrial efforts to develop high-performance carbons and carbon-based devices have assumed much importance in the last few years.

**Carbon is a very interesting and unique element in the periodic table. It exists under few allotropic forms, but what is most interesting is that in its $sp^2$ hybridization state it presents am unlimited number of nano-textural arrangements giving rise to extremely varying physical properties (mechanical properties, electrical conductivity, porosity, etc.). Carbon as a material is constituted not only of carbon, but also of heteroatoms such as oxygen, nitrogen, and hydrogen, which are generally present as surface functional groups at the edges of the graphene layers. The properties of carbons, in particular the electrochemical ones, are influenced by the surface functionality. Carbons can be found in various forms or morphologies (e.g. powders, fibers, spherical, particles, monoliths, and nanotubes), which allow them to be adapted for a large number of industrial applications. Any other known material does not match this high versatility of carbon. Finally yet importantly, most carbon materials can be produced from available precursors through simple processes. In summary, carbon is a very suitable material for electrochemical applications because of its low cost, high electrical conductivity, versatile nanotexture, and surface functionality. It has been playing a significant role in the development of alternative clean and sustainable energy technologies due to their unique properties.**

This course summarizes the structural properties and classification of carbon materials, recent techniques on the synthesis of porous carbons and their application in energy storage and conversion. In particular, we will systematically discuss the porous structure, surface chemistry and electrical properties of carbons as electrode materials for supercapacitors, lithium-ion batteries, fuel cells, and other energy conversion devices. The common challenges in developing simple, scalable, and environmentally friendly carbon materials and manufacturing processes, in controlling the nanoscale and high-level structures and functions, and in integrating such materials with suitable device architectures will be reviewed. Recent application in the area will be also discussed.