# Coal and Biomass Char Reactivity

**Investigators:** Reginald E. Mitchell, Associate Professor, Mechanical Engineering; Liqiang Ma, Graduate Researcher

**Sponsor:** Global Climate and Energy Project

**Objective:** The goal of this project is to provide the information needed to characterize the fundamental chemical and physical processes controlling coal-char and biomass-char conversion to gaseous species in the type environments likely to be established in advanced gasifiers, boilers and furnaces.

There is considerable concern regarding the potential global environmental impact of fossil fuels used for power generation. By increasing the fraction of renewable energy in the national energy supply, some of the impact can be mitigated. Co-firing biomass with coal in traditional coal-fired boilers or using biomass as a reburn fuel in advanced coal-fired boiler configurations represent two options for combined renewable and fossil energy utilization. Gasification of the biomass offers additional options. Design of boilers, reburners and gasifiers requires an understanding of processes that control the physical transformations that fuel particles undergo when exposed to hot, oxidizing environments and the chemical reactions responsible for conversion of the solid material to gaseous species and ash. The effort will result in fundamentals-based sub-models for particle mass loss, size, apparent density, and specific surface area evolution during char conversion.

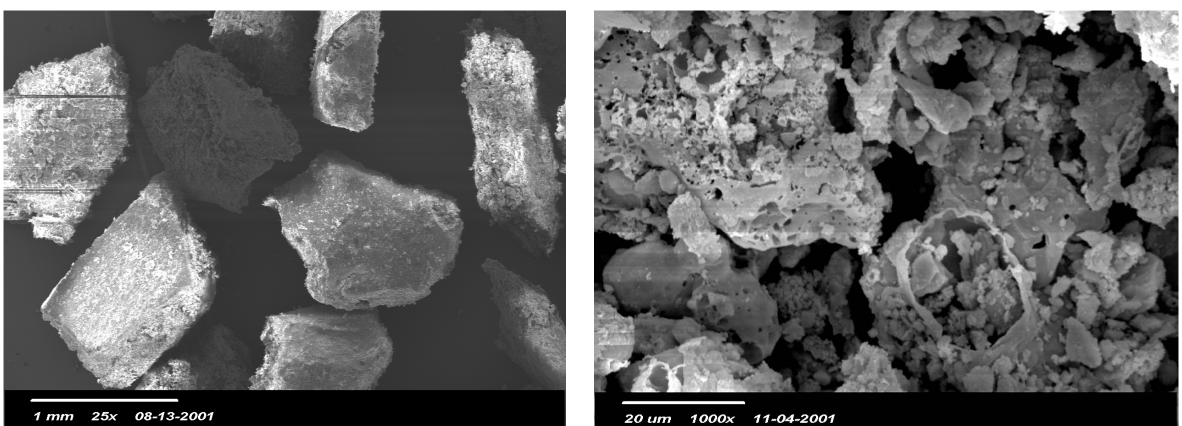
**Background:** The physical characteristics and chemical composition of biomass material influence how it can best be utilized. Upon rapid heating, some biofuels have high gas yields, rendering them suitable for gasification and reburn applications. Other biofuels have high char yields, and are better-suited for co-firing in direct combustion configurations. With the proper choices of biomass, coal, boiler design, and boiler operation, reductions in pollutant and net greenhouse gas emissions can be realized.

The key compounds in biomass materials are cellulose, hemicellulose, and lignin; therefore the materials selected for examination will vary in the contents of these key compounds. Hardwoods generally have high hemicellulose and low lignin contents and softwoods have relatively low hemicellulose and low lignin contents. Besides woods and various straws, materials selected for study will include wastes of such biomass treating industries as the wood-processing industry, the paper and pulp industry, and the food industry. Tests to measure the reactivities of chars produced at high heating rates from cellulose, hemicellulose and lignin will also be performed. The objective of one of the planned studies is to assess the extent to which the reactivity of a biomass char can be predicted based on its fractional contents of cellulose, hemicellulose, and lignin and the reactivities of the high-heating-rate chars produced from these pure compounds.

**Approach:** Chars characteristic of those created at high temperatures and heating rates in real coal-fired boilers and furnaces are produced in a laminar flow reactor in which is established a high-
temperature environment (from 1300 to 2000 K) of specified oxygen content (from 3% to 12% by mole $O_2$). Partially reacted chars extracted from the flow reactor at selected residence times provide samples for analysis to determine char physical and chemical properties as functions of char conversion.

The extracted char samples are subjected to a variety of tests to determine the conversion rates in the high-temperature flow reactor environments as well as to determine apparent densities, specific surface areas, and intrinsic chemical reactivities to oxygen as functions of particle size distributions. Particle size distributions are measured using a Coulter Multiziser, an instrument that measures the size distributions of particle suspensions using an electroresistive method. Specific surface area measurements are made using gas adsorption techniques employing $CO_2$ as the adsorption gas at 298 K. The reactivity tests are performed in a thermogravimetric analyzer (TGA) under chemical kinetics-controlled oxidation conditions.

As an example of the capability available, scanning electron micrographs (SEMs) of raw and partially reacted almond shell particles are shown in Figure 1 along with mass loss and specific surface area measurements. The raw, unreacted almond shell particles used in the tests were screened to eliminate particles larger than about 1 mm in size. The particles contained 37% ash, by weight. The partially reacted char shown in the SEM was extracted 33 ms after injection into a flow reactor environment containing 8% by mole $O_2$ at nominally 1243 K.




t = 0 ms: $m/m_0 = 1.0$, $S_{gp} = 25\ m^2/g$ t = 33 ms: $m/m0 = 0.42$, $S_{gp} = 20\ m^2/g$

**Figure 1:** Scanning Electron micrographs of (left) raw almond shell particles and (right) one of its partially reacted chars

To provide insight into the influence of char chemical make-up on rates of oxidation, coals of various ranks and biomass of various origins must be tested. In addition, to provide insight into the impact of ash on the properties of the chars produced, feedstocks having a range of ash contents will have to be tested. Data to characterize the impact of pressure on coal and biomass devolatilization yields, initial char particle morphology, and oxidation rates will be obtained by performing experiments over a range of pressures at fixed temperatures.

This work will develop a greater understanding of how biomass properties influence char conversion rates and to characterize the physical changes that char particles undergo during gasification. The data will permit the development and validation of the physical and chemical sub-models used in comprehensive models for coal-fired and biomass-fired process units. The comprehensive models can be used to investigate potential design strategies and can help define optimum operating conditions that benefit coal and biomass conversion processes.

**Contact:** remitche@stanford.edu