Energy demand is expected to grow by 20% over the next 10 years. In order to account for this increase in energy consumption, new and novel combustion techniques are required to mitigate the effects of pollution and fossil fuel dependency. Oxy-fuel combustion in supercritical carbon dioxide (sCO2) cycles can increase plant efficiencies up to 52% and reduce pollutants such as NOX and CO2 by 99%. Supercritical engine cycles have demonstrated electricity costs of $121/MWh, which is competitive in comparison to conventional coal ($95.60/MWh) and natural gas power plants ($128.4/MWe). This increase in efficiency is mainly driven by the near-liquid density of the working fluid (sCO2), in the supercritical regime, before entering the turbine for energy extraction of the high pressure and high density sCO2 gas. In addition, supercritical CO2 engine cycles produce near-zero air emissions since CO2, a product of combustion, is the working fluid of the system which can be regenerated to the combustor. The predictive accuracy and lack of combustion models in highly CO2 diluted mixtures and at high pressures is one the major limitations to achieving optimum design of supercritical engine combustors. Also, most natural gas mechanisms and validation experiments have been conducted at low pressures (typically less than 40 atm) and not in CO2 diluted environment. Thus experimental data is important for the development of modern combustion systems from work focusing on supercritical carbon dioxide cycles to rotational detonation engines. This thesis presents the design of the shock tube and two optical diagnostic techniques for measuring ignition delay times and species time histories using a shock tube in CO2 diluted mixtures. Experimental data for ignition delay times and species time histories (CH4, CO) were obtained in mixtures diluted with CO2. Experiments were performed behind reflected shockwaves from temperatures of 1200 to 2000 K for pressures ranging from 1 to 11 bar. Ignition times were obtained from emission and laser absorption measurements. Current experimental data were compared with the predictions of detailed chemical kinetic models (available from literature) that will allow for accurate design and modeling of combustion systems.