In the light of depleting fossil fuel resources, importance of research related to alternative fuel utilization in internal combustion (IC) engines is gaining prominence. During the last two decades, natural gas fuelled vehicles have been promoted extensively because of their lower emissions, both regulated as well as unregulated. Tighter emissions norms have compelled engine researchers to think about lean burn concept along with efficient alternate ignition source. CNG vehicles fuelled with lean mixtures face challenges such as of lower flame speed, leading to reduced power output. Use of leaner mixture requires use of higher voltage for successful spark ignition of charge without misfire. However use of higher voltage leads to issue in conventional spark ignition (SI) systems such as high electrode erosion. In-cylinder turbulence may extinguish such weak spark, thus restricting flame growth due to presence of electrodes. These practical problems can be overcome by using laser as an ignition source. The laser plasma is significantly more intense and its temperature is two orders of magnitude higher and pressure is one order of magnitude higher compared to plasma generated by conventional electrical spark plug. Therefore laser ignition (LI) coupled with used of natural gas and hydrogen, has emerged as a prominent solution to combat energy crises by developing an efficient ignition system for the engine used in transportation sector. This experimental study aims to assess the challenges and benefits of using hydrogen enriched compressed natural gas (HCNG) blends as fuel and laser as the source of ignition in a prototype IC engine. Experiments in this study were conducted in two phases. In the first phase of experiments, a constant volume combustion chamber (CVCC) was used for the study of fundamental aspects of LI. In the second phase of experiments, an engine experimental setup was developed to compare LI vs. SI systems for HCNG blends for their combustion, performance and emissions characteristics. Fuel was introduced using a port fuel injection system in the prototype HCNG fuelled engine. In this study, HCNG mixtures were investigated for different lambdas (λ) ranging from rich to lean fuel-air mixtures, using a Q-switched Nd:YAG laser (200 mJ; 30 Hz; 6-9 ns) in the CVCC. Experiments were conducted at different ambient pressures of 5 bar and 10 bar. These pressures simulated the in-cylinder pressures at the time of spark ignition in an engine cycle. Flame kernel evolution in HCNG blends of varying compositions (10%, 20%, 30%, and 40% v/v hydrogen) were compared with baseline CNG for a specified λ.

A high speed CCD camera was used for triggering the laser and the data acquisition system. Flame kernel evolution was recorded using shadowgraphy technique. Images were captured at 54000 fps and further analyzed to obtain temporal propagation of flames in different orthogonal directions. It was noted that for any typical initial chamber pressure, Pmax during combustion reduced with increasing λ. Both peak pressure and flame speed were observed to be higher at $\lambda = 1.1$ for HCNG mixtures. Knocking or two-stage combustion phenomena increased with increasing initial chamber pressure from 5 bar to 10 bar as well as increased H_2 fraction in the HCNG mixtures. Increased H_2 fraction in HCNG mixture not only speeds up flame kernel evolution but also shifted the flame kernel development from a two dimensional phenomenon to a three dimensional (volumetric combustion phenomenon). After detailed CVCC investigations of different HCNG mixtures, LI was evaluated in a production grade engine. The purpose of LI of engine was also to establish the qualitative correlation between the results of CVCC and the engine. In these experimental investigations, engine was fuelled with HCNG-air mixtures as well as H_2-air mixtures and CNG-air mixtures. Initially, engine investigations were performed using a conventional electric spark plug to optimize operating parameters for different HCNG blends at different λ under NA condition with varying the throttle. For LI, converging lens with 50 mm focal length was used to focus the laser beam inside the engine combustion chamber. Initially, spark timing was tuned to obtain permissible CCV, higher engine output, lower emissions and higher BTEs at all engine operating points. H2 enrichment of CNG obviously helped to reduce the COVIMEP, when the spark timing was retarded from the MBT spark timing as well as for leaner mixtures. Lean burn limit extended due to H2 addition to CNG and optimized spark timing enhanced combustion stability along with improving its engine performance. 30HCNG showed lower COVIMEP for both SI and LI. COVIMEP were below 6% for all HCNG blends. Brake thermal efficiency was higher with LI compared to SI. The extended lean burn limit was $\lambda = 1.5$ for CNG and 10HCNG, $\lambda = 1.6$ for 20HCNG, $\lambda = 1.7$ for 30HCNG, $\lambda = 1.8$ for 40HCNG and $\lambda = 2.5$ for H2 in case of LI. Engine was then operated in supercharged condition (SC) and engine combustion, performance and emissions characteristics were evaluated. Due to boosting, heat release curve flatted, which resulted in lower RoPR, peak pressure and temperature during combustion. BTE increased and BSFC reduced up to optimum boosting level and then BTE decreased and BSFC increased with further increase in boosting level. Increased BTE indicated higher power output form the engine which reduced due to lean engine operation. LI delivered slightly better performance compared to SI. EGT reduced with increased boosting and LI showed lower EGT compared to SI. Boosting resulted in slightly higher BSHC and BSCO emissions due to lower in-cylinder temperature using LI. Lower EGT in LI resulted in lower BSNOx emissions but it increased with increasing H/C ratio of test fuel. BSNOx emissions reduced by 50% for 0.1 bar boost with LI. LI system delivered superior engine performance using HCNG mixtures and reduced NOx emissions significantly, thus reducing/ eliminating the need for exhaust gas after treatment.