# Summary

This doctoral thesis scrutinises in detail multiple aspects concerning the use of hydrogen in Internal Combustion Engines (ICEs), as a suitable alternative to conventional liquid fuels such as gasoline and diesel. The achievements of the last three years of research activity performed by the author are resumed within this text. The scientific contribution to the treated topic is supported by the results obtained by applying different techniques and methodologies. The reason for this activity is probably well known to most readers; for those not completely familiar with this specific research field, the question can be broadly resumed with a single word: transition. Transition because hydrogen is part of a larger process, full of uncertainties and consequent mutable scenarios which render quite difficult to predict exactly what role it will play. Therefore, hydrogen occupies a delicate "position", where the line between practical application and theory is very thin and debated in many scientific papers. Experimental activities constitute the core of this thesis, and they covered multiple aspects that ranged from the fundamental analysis of gaseous jet distribution through the use of a sophisticated optical technique, i.e. particle image velocimetry (PIV), to the practical application of hydrogen in an optically accessible single cylinder engine. In this way, the discussion covers both non-reacting (PIV) and reacting ($H_2$-ICE) activities.

The non-reacting investigations implied the use of helium gas as a hydrogen substitute. Experimental tests were carried out inside a constant volume chamber with an injector mounted on the top wall. The injector modularity made it possible to change the tip with three different nozzle geometries. Depending on the operating conditions, the injection pressure ranged from a minimum of 5 up to 20 bar, while the pressure inside the chamber was swept from atmospheric to 7 bar. Green light from a dual cavity Nd:YAG laser was used as luminous source and a 4-megapixel PIV-camera for the image capture. Vegetable oil particles have been seeded inside the chamber and used as particle tracers. The test campaign planned during the research stage period at Chalmers University of Technology, involved the acquisition of a large dataset. Given the technical characteristics of the injector, most of the selected cases featured low-pressure conditions, representative of fuel delivery during the intake stroke; tests with higher injection pressure can be seen as closer to injection during the compression stroke, i.e. with the intake valves closed. The large number of conditions resulted in a comprehensive analysis capable of providing valuable insight on the role of nozzle tip geometry, as well as the capability of a certain configuration to ensure longer jet penetration or the formation of vortex structures that improve air entertainment.

The reacting analysis (i.e. combustion in a spark ignition engine) was implemented as part of two different experimental test campaigns. The first set of operative conditions entailed the use of hydrogen - methane blends (in various ratios); the second set of data involved the use of pure hydrogen as fuel. $H_2$ delivery (as well as that of $CH_4$–$H_2$ blends) was performed via port fuel injection (PFI) and the engine speed was varied from 1000 to 2000 rpm. The duration of injection was swept to ensure a relative air-fuel ratio ($AFR_{rel}$) range from 1.9 to 3.6. The experimental setup allowed digital imaging to be applied in cycle resolved mode by using a CMOS high speed camera, and natural emission spectroscopy was implemented with an ICCD camera coupled with a spectrometer. The digital imaging data was used for the evaluation of flame front properties in terms of morphological parameters and how these variables relate with the cycle-to-cycle evolution of combustion. This analysis covered the process from kernel inception to the fully developed flame stage, thus providing comprehensive understanding of flame development patterns. Optical Emission Spectroscopy (OES) was employed for identifying atomic and molecular species; specifically, Spark Induced Breakdown Spectroscopy (SIBS) was implemented for the investigation of molecular $H_2$ related emissions. Balmer $\alpha$ and Fulcher $\alpha$ bands were examined throughout the ignition phase after spark timing and their intensity correlated to the local fuel concentration.