THERMOCHEMICAL CONVERSION OF SMART ENERGY CARRIERS IN SCALE-BRIDGING SYSTEMS

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The world energy sector is currently facing the constraints to reduce the Green Houses Gases (GHG) emissions due to the global warming acceleration. The World Energy Outlook 2018 identified the global energy trends and their potential impact on supply and demand, carbon emissions, air pollution and energy access. The performed analyses highlighted that, under current and planned policies, the energy demand is expected to grow by more than 25% to 2040, undergoing the electricity market to a huge transformation because of the increasing demand due to the digital economy, electrification in transport sector and other technologies.

In this framework, a global energy transition based on Renewable Energy Source (RES) integration in the energy production system is mandatory to face the growing energy demand while contributing at the same time to the reduction of pollutant emissions and decarbonization.

In order to achieve such integration, the intermittency and seasonality of renewable energy sources requires the development of specific processes and technologies able to mitigate inherent RES variability, thus allowing their sustainable deployment on a global scale.

At present, there is a range of existing mechanical, chemical, thermal and electrical technologies for storing the surplus of renewables. Despite that, most of them still present considerable limitations that hinder their direct application in the current energy scenario. Batteries are not able to provide the required capacity for grid-scale energy storage because their narrow energy density and short discharge time. Pumped hydro and methods such as compressed gas energy storage have enough commercial maturity but they suffer from geological constraints to their deployment. Instead, chemicals-based storage offers the advantage of storing large amounts of energy for long periods, with high efficiency and at any location, ensuring both easy and safe transportation and storage. In this context, ammonia, bio-derived molecules, hydrogen, are increasingly considered a feasible solution to store the energy surplus of renewables sources.

Strongly linked to the RES integration in the energy industry sector, it is needed to develop an energy supply system able to efficiently exploit the large class of available energy carriers used to store the RE. In this regard, a *combustion-supported* energy supply system is considered, due to the characteristic of combustion based system in terms of reacting times, duration and power capacity to be supplied.

This objective requires the development of advanced combustion technologies that simultaneously realize fuel/load flexibility, high efficiency and very low pollutant emissions.

An efficient technology matching these issues is the MILD combustion, an advanced combustion technology based on the concept of burned gas recirculation and hence dilution of fresh gases. Such technology is capable of ensuring simultaneously high thermal efficiency and reduced pollutant emissions, while responding to the resilience and flexibility with respect to operational conditions and fuel properties. This combustion regime strongly differs from traditional combustion cases, showing a distributed reaction region that ensures homogeneity of temperatures and species inside the reactor volume, absence of a visible flame front and moderated emissions of main pollutants.

In this context, this thesis aims to investigate and optimize the thermochemical conversion under MILD combustion conditions with respect to the potential use of innovative energy carriers (ammonia, alcohols, hydrogen and their blends) in a lab-scale burner.

In particular, a cyclonic combustion chamber will be used as a bridge-scale reactor with the two-fold scope of characterizing the reactive process with several fuels and validate numerical models on the basis of the experimental results on a lab-scale system that contains information of both the elementary processes and industrial scale.

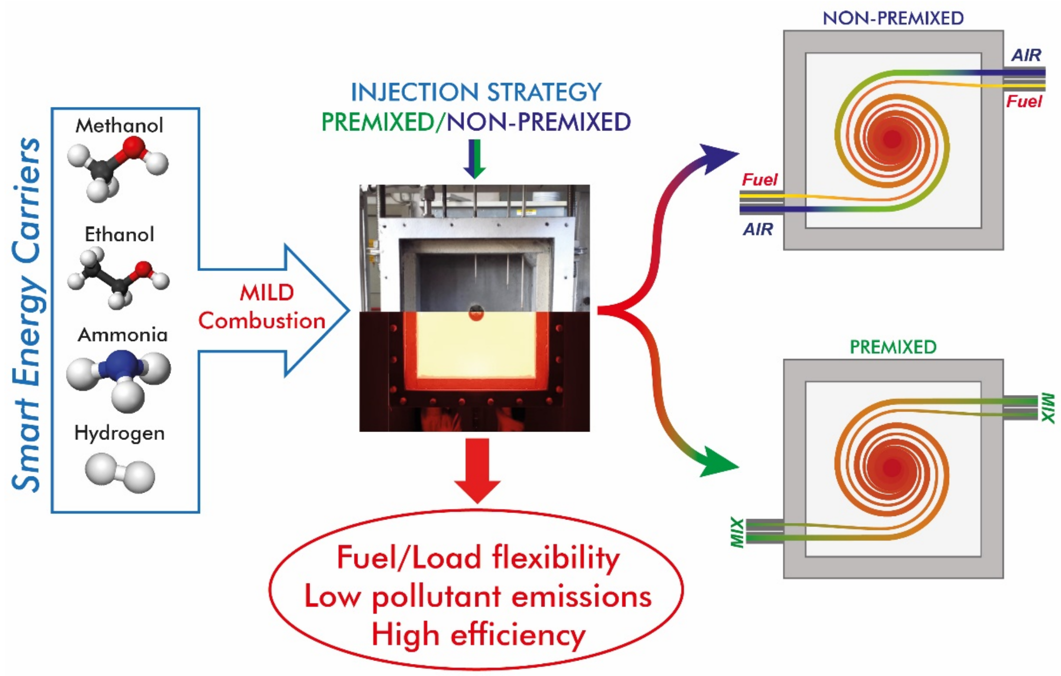
To this aim, a strategy based on focused experimental campaigns and numerical analysis will be pursued for the development of a resilient and fuel flexible MILD combustion process, directly linked to several industrial applications.

The obtained results will provide very useful insights on the reactive process for the development of advanced thermochemical conversion systems that are able to utilize innovative smart energy carriers in several plants.

In fact, these molecules play a crucial role for the transition toward a green energy production system based on the integration of renewable energy sources, in compliance with circular economy concept. Ammonia, hydrogen, bio-derived compounds (alcohols), alone or blended with conventional fuels, are essential to this shift. A successful exploitation of these fuels require the availability of a thorough knowledge on their thermochemical conversion.

The focus in this PhD thesis is on the MILD combustion due to its efficiency and very low pollutant emissions. In these processes oxidation stabilization relies on auto-ignition phenomena, sustained by relevant exhausts recirculation, giving rise to very peculiar process with unique physical-chemical properties. MILD combustion have been already demonstrated for its use with conventional fuels. However, they appear to be an optimal choice for the above-mentioned innovative energy carriers.

The objectives of the thesis are the experimental study of ammonia, alcohols, hydrogen and their blends, also in comparison with traditional fuels, in a lab-scale cyclonic burner, available at STEMS, as a function of the main operational parameters (i.e. mixture equivalence ratio, reactant feeding strategy, preheating and dilution level). A parallel numerical study of chemical kinetics and fluid-dynamics will be performed to identify the key factors controlling the chemical and physical phenomena occurring under MILD conditions.



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