Green metals as recyclable carriers of renewable energy – From global opportunities to combustion physics

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Abstract

The transformation to a net-zero carbon society is one of the most pressing challenges of our time. Green metal fuels, produced from metal oxides using renewable energy, are emerging as a carbon-free, high energy density replacement for fossil fuels due to their availability and recyclability. Iron in particular is a promising option for a carbon-free cycle since it is non-toxic, safe to transport, easy to store, abundant, and in principle can be recycled an unlimited number of times.

This plenary will deliver two key messages:
1. Metal fuels are a promising carrier of renewable energy for a net-zero carbon society.
2. While previous work on solid carbonaceous fuels provides an excellent starting point for studying metals as energy carriers, the physics of metal fuel combustion is quite different, fascinating, and largely unexplored.

In the first part, iron as a metal fuel is first introduced as a recyclable chemical energy carrier. During the reduction of iron oxides, energy from renewable sources such as wind, hydro, and solar is stored. This energy is released again through combustion and can be used as high-temperature process heat or for the generation of electricity. The product of this zero-CO2 combustion process is solid iron oxide, which can be collected for recycling. One promising application of metals is the retrofit of existing infrastructure. This is demonstrated with a thermodynamic system analysis for a coal-fired power plant to be operated with iron powder in the future. This is followed by a techno-economic analysis, for which different partner countries for reduction and oxidation are considered. Hydrogen and iron are compared as energy carriers on the basis of round-trip efficiency and levelized cost of electricity.

In the second part, selected experimental and numerical results on the combustion physics of iron are presented. First, the oxidation of single iron particles is showcased, and the different phases of ignition and combustion are discussed with a special focus on the coupling of gas phase transport with the condensed phase kinetics. Next, canonical polydisperse iron-air flames, from which typical combustion characteristics such as the reaction front speed can be deduced, are discussed. Going towards multidimensional flames, experimental and numerical results for a laminar self-sustained Bunsen-type jet flames are presented. The reaction zone structure and the reaction front speed are analyzed. The need for well-controlled and well-characterized experimental conditions to reduce uncertainties is demonstrated by comparison to simulation results. Finally, results for turbulent iron-air flames are presented.

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