Electrification of chemical industry: a key role for plasma chemistry

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Sustainable energy generation by means of wind or from solar radiation through photovoltaics or concentrated solar power will continue to increase its share of the energy mix. Intermittency due to e.g. day/night cycle, regional variation in availability, and penetration of sustainable energy into sectors other than electricity such as the chemical industry necessitates means of storage, transport and energy conversion on a large scale. A promising option is the synthesis of chemicals and artificial fuels using sustainable energy. A truly circular economy requires that the raw materials are the thermodynamically most stable ones such as CO$_2$ and N$_2$. In this contribution it will be highlighted how plasma chemistry can potentially combine compatibility with e.g. intermittency and localized production to activate these molecules with maximum energy efficiency, essentially due to preferential vibrational excitation (causing inherently strong out-of-equilibrium processing conditions that achieve selectivity in the reaction processes). Examples will be discussed of research carried out at DIFFER to ultimately enable a scale up to chemical industrial applications.

A common microwave reactor approach is evaluated experimentally with laser Rayleigh and Raman scattering (to assess gas and vibrational temperatures) and Fourier transform infrared spectroscopy (yielding conversion and efficiency). For example, 50% energy efficiency was observed in pure CO$_2$ (forming CO and O$_2$) in a thermodynamic equilibrium conversion regime governed by gas temperatures of ~3500 K. These results are interpreted on basis of Boltzmann solver based plasma dynamics estimates, indicating that intrinsic electron energies are higher than what is favourable for preferential vibrational excitation. Pulsed experiments (1-5 kHz) in which gas temperature dynamics are revealed confirm this picture. In pure N$_2$, vibrational temperatures are observed in excess of 10000K and up to five times higher than the gas temperature. The signature of the Treanor effect (overpopulation of higher levels) is confirmed. These observations are promising in view of economic localized production of fertilizer. Finally, an outlook is given to novel reactor approaches that tailor the plasma dynamics to optimally promote vibrational excitation and to achieve the desired non-equilibrium.