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Power-to-gas and the consequences: impact of higher hydrogen concentrations in natural gas on industrial combustion processes

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Abstract

Operators of public electricity grids today are faced with the challenge of integrating increasing numbers of renewable and decentralized energy sources such as wind turbines and photovoltaic power plants into their grids. These sources produce electricity in a very inconstant manner due to the volatility of wind and solar power which further complicates power grid control and management. One key component that is required for modern energy infrastructures is the capacity to store large amounts of energy in an economically feasible way.

One solution that is being discussed in this context is “power-to-gas”, i.e. the use of surplus electricity to produce hydrogen (or even methane with an additional methanation process) which is then injected into the public natural gas grid. The huge storage capacity of the gas grid would serve as a buffer, offering benefits with regards to sustainability and climate protection while also being cost-effective since the required infrastructure is already in place.

One consequence would be, however, that the distributed natural gas could contain larger and fluctuating amounts of hydrogen. There is some uncertainty how different gas-fired applications and processes react to these changes. While there have already been several investigations for domestic appliances (generally finding that moderate amounts of H_2 do not pose any safety risks, which is the primary focus of domestic gas utilization) there are still open questions concerning large-scale industrial gas utilization. Here, in addition to operational safety, factors like efficiency, pollutant emissions (NO_X), process stability and of course product quality have to be taken into account.

In a German research project, Gas- und Wärme-Institut Essen e. V. (GWI) investigated the impact of higher and fluctuating hydrogen contents (up to 50 vol.-%, much higher than what is currently envisioned) on a variety of industrial combustion systems, using both numerical and experimental methods. The effects on operational aspects such as combustion behavior, flame monitoring and pollutant emissions were analyzed.

Some results of these investigations will be presented in this contribution.

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1. Introduction

Global warming and the emission of so-called greenhouse gases (GHG) such as carbon dioxide (CO_2) is considered to be one of the central challenges of the 21st century. At the same time, the worldwide demand for electricity increases due to the growing world population and improving living conditions in many parts of the world. In the industrialized countries there is a discussion going on how to prepare economies and existing energy infrastructures for a low-carbon future, i. e. without heavily relying on carbonaceous fuels such as coal, mineral oil or natural gas.

In Europe, much of this discussion centers on the generation and distribution of electricity, often with distinct national flavors. In Germany, for example, the “Energiewende” aims to compensate the phasing out of nuclear power generation with a corresponding increase in power generation from renewable sources such as wind and solar power. Even in traditionally pro-nuclear nations such as France, the need is acknowledged to integrate renewable and sustainable energy sources into the energy infrastructures to greater extent than in the past as part of the “transition énergétique” [1], [2].

One challenge in this context is that by their very nature, energy sources such as wind and solar power are dependent on local meteorological conditions such as day and night, cloud coverage or wind speeds. Electrical energy on the other hand, cannot be easily and economically stored in large amounts; instead, electrical grids have to balance supply and demand almost continuously and their storage capacity is generally rather limited. Thus, one technological challenge is how to deal with surplus electricity in times of high supply, and at the same time be able to provide sufficient electricity for all end-users in times of high demand.

Also, the local and regional balances of supply and demand are likely to shift dramatically if renewable energy sources are integrated into the electricity grids in great numbers: in Germany, for example, wind turbines are primarily being erected in the northern parts of Germany due to the better meteorological conditions there. But the energy consumers, i. e. the main population centers and industrially strong regions, are located in the west or the south for the most part. This means that large amounts of electricity will have to be transmitted along the entire length of the country. The existing grid infrastructure is not equipped to handle this.

A promising solution to these problems is the so-called “power-to-gas” approach [3], [4]. In times of high electricity production from renewable sources, surplus electricity is used to power an electrolyzer to produce hydrogen from water. This hydrogen can either be stored and used locally on demand to produce electricity in fuel cells or gas engines, or it could be fed, directly or after an additional methanation step to convert hydrogen into methane, into the natural gas grids. The advantage of this approach is that it is relatively easy to store large quantities of gas. In total, the German natural gas grid has a storage capacity of about 220 TWh [5] while the German electricity grid only has a storage capacity of about 0.4 TWh. Thus, “power-to-gas” could help relieve electricity grids and reduce the necessary, yet often unpopular expansions of the existing electricity infrastructures.

2. Hydrogen in natural gas

From a purely energetic point of view, it is better to inject the hydrogen directly into the gas grid since the methanation step incurs some efficiency loss. On the other hand, though, there are millions of residential appliances and large-scale industrial and power generation processes connected to the gas grid. It has to be ensured that these end-use applications do not suffer negative consequences in terms of safety, efficiency or pollutant emissions. The same is obviously true for the gas infrastructure itself where some investigations have already been carried out, such as [6], [7]. The opinions about benefits and risks of hydrogen injection into the gas grids differ: some see much promise and only little risk for end-users or infrastructure in this approach [8], [9], [10] while others are more skeptical and refer to potential drawbacks [11], [12].