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# Pathways to Low Carbon Hydrogen

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## Abstract

The transition to a sustainable energy future necessitates advanced solutions for reducing greenhouse gas emissions while maintaining energy reliability and scalability. Low carbon hydrogen, produced from natural gas reforming paired with carbon capture and storage (CCS) technologies, can play a key role as intermediary in this energy transition. In this presentation, we explore the processes and potential of low carbon hydrogen production from the viewpoint of an industrial gases and engineering company.

An overview of existing routes for the production of hydrogen on an industrial scale is provided, and the $CO_2$ reduction potential is compared. Hydrogen is primarily produced via steam methane reforming (SMR) or autothermal reforming (ATR), processes that extract hydrogen from methane while releasing carbon dioxide as a byproduct. By integration of CCS technologies majority of the CO2 can be captured , preventing its release into the atmosphere and mitigating the environmental footprint of low-carbon (blue) hydrogen production. A current Linde project is presented as an example of this type of low-carbon hydrogen production.

High activity is observed in the field of new developments based on ammonia cracking for hydrogen production on an industrial scale. This method relies on ammonia being produced from zero- or low-carbon hydrogen at renewable favored locations. The key advantage of ammonia is, that no carbon is involved. It can be produced from air nitrogen and low carbon hydrogen. Furthermore, it has a high specific hydrogen content and the transport infrastructure is available and mature. Nevertheless, challenges arise from the combination of material requirements, burner operation, emission management, and the selection of appropriate catalysts. Linde's activities in the HyPAC project are highlighted.

Renewable energy-driven water electrolysis offers a zero-carbon (green) alternative however still struggling with technology readiness and availability of affordable electric power prices. Different electrolyzer technologies are presented and linked to current projects and R&D activities.

Low carbon hydrogen serves as a transitional solution, enabling a more immediate and impactful reduction in carbon emissions at large scale while renewable energy grids and green hydrogen infrastructure are upscaling and developing. By addressing technical and economic hurdles and increasing investment in CCUS advancements, blue hydrogen can play an instrumental role in achieving net-zero emissions targets.