Alternative Technologies for Hydrogen Supply in the Framework of Decarbonization of Manufacturing Industries

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The decarbonization of energy-intensive manufacturing sectors - such as steel, cement, and chemicals - represents one of the most pressing challenges in the transition toward a low-carbon economy. These so-called "hard-to-abate" industries rely heavily on fossil fuels, particularly natural gas, for high-temperature processes and feedstock needs. As such, they contribute significantly to global greenhouse gas emissions and present complex obstacles to conventional emission-reduction strategies. To meet climate goals, it is essential to identify and implement alternative energy solutions that are not only low-carbon but also safe, reliable, and industrially scalable. Hydrogen has emerged as a key energy carrier capable of playing a central role in this transition. Its flexibility in both energy supply and chemical applications makes it a promising substitute for natural gas in a wide range of industrial uses. However, adopting hydrogen on a large scale requires careful consideration of multiple factors - including safety, sustainability, and operational practicality. These aspects become even more critical when hydrogen is introduced into existing infrastructures or high-risk industrial contexts.

This study investigates the transition from natural gas to hydrogen in a high-temperature industrial site through the analysis of several alternative hydrogen supply technologies. A comparative case study is analyzed, considering multiple scenarios: from traditional hydrogen transportation methods (e.g., trailer-based supply) to emerging on-site production and generation technologies. Each scenario is evaluated using a multidisciplinary framework that integrates safety assessment, environmental sustainability indicators, and technical feasibility. The methodology combines qualitative and quantitative tools to assess trade-offs across different supply configurations. Safety considerations include both process-related hazards and potential domino effects in an industrial environment. Sustainability is analyzed in terms of carbon footprint, resource consumption, and life cycle implications, while technical feasibility assesses infrastructure compatibility, energy requirements, and operational reliability. The results offer a comparative perspective on the advantages and limitations of each hydrogen supply route, with a particular focus on how they align with broader decarbonization objectives. The study provides actionable insights for stakeholders - such as industrial operators, policy-makers, and technology developers - seeking to adopt hydrogen in a safe, sustainable, and efficient manner. By presenting a structured decision-making framework and highlighting real-world implications, this work contributes to the growing body of knowledge supporting the practical implementation of hydrogen technologies in hard-to-abate sectors, paving the way for safer and more climate-resilient industrial systems.

Keywords: *Hydrogen, Energy transition, Alternative technologies, Safety, Sustainability, Manufacturing industries*