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*Article*

# Applications of Synthesis Gas and Hydrogen in the Chemical Industry

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**Abstract:** The production of hydrogen and synthesis gas from hydrocarbon feedstocks is a priority task for the petrochemical and energy sectors due to the increasing demand for clean and versatile energy carriers. Conventional steam reforming processes based on nickel catalysts are widely used for hydrogen and synthesis gas production; however, their practical application is complicated by catalyst deactivation caused by coke deposition, sintering of the active component, and poisoning by sulfur-containing compounds. These limitations require extensive purification of hydrocarbon feedstocks and increase the operating and technological costs of reforming processes. Therefore, the development of efficient and economically viable catalysts capable of maintaining high activity and stability under severe reaction conditions is of significant scientific and practical interest. Particular attention can be given to catalysts supported on natural mineral materials, including vermiculite and vermiculite ore, as well as modified alumina-based systems. The use of such supports may improve the dispersion and stabilization of nickel-containing active components, enhance the thermal and mechanical stability of the catalyst, and provide favorable structural characteristics for reforming reactions. The present study focuses on the development and evaluation of nickel-based catalytic systems for the steam reforming of hydrocarbon feedstocks, including heavy oil residues, petroleum pitch, and resin-containing materials.

**Keywords:** hydrogen, synthesis gas, nickel catalyst, hydrocarbon feedstock, steam reforming, steam methane reforming, vermiculite, vermiculite ore, gamma-alumina ($\gamma$-$Al_2O_3$), heavy oil residues, petroleum pitch, resin, hydrogen sulfide ($H_2S$).

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## 1. Introduction

One of the priority tasks in the fields of chemistry and energy is the development of efficient methods for producing hydrogen and synthesis gas, which rank among the most environmentally friendly energy carriers.

Processes for converting hydrocarbon feedstock into hydrogen and synthesis gas (reforming) are considered industrially significant operations for producing key energy carriers in all developed nations. The industrial catalysts employed in the reforming process primarily consist of nickel

compounds impregnated into various complex systems based on aluminum oxide.

The harsh conditions of the steam reforming process impose a specific set of requirements on both the catalysts themselves and their supports. Steam reforming catalysts are evaluated based on a combination of properties: activity, selectivity, thermal and chemical stability, mechanical strength, and hydraulic resistance [1].

The primary negative factor affecting catalyst activity is carbon formation, which typically leads to a decline in activity and catalyst deactivation [2]. Deactivation can also occur through the poisoning of the catalyst's active sites—resulting in the formation of inactive metal sulfides—during the desulfurization of the feedstock. Consequently, one of the key requirements for steam reforming catalysts used with hydrocarbon feedstocks is their resistance to sulfur compounds.

## 2. Materials and Methods

The The study was conducted as a literature-based analytical review of published scientific and technical information concerning the production and utilization of synthesis gas and hydrogen in the chemical industry [3]. The reviewed material was organized according to the principal hydrocarbon reforming routes, catalyst requirements, feedstock types, and major industrial applications of synthesis gas and hydrogen.

The analysis considered information on steam reforming, partial oxidation, autothermal reforming, plasma-catalytic reforming, gasification, pyrolytic conversion, biological conversion, electrolysis, and photocatalytic and chemical conversion routes. Particular attention was given to nickel-containing reforming catalysts supported on aluminum oxide, catalyst deactivation caused by carbon deposition, and poisoning by sulfur compounds.

The literature sources cited in the original manuscript, including works by Song (2006), Shidakova and Starodubtseva (2014), Larminie et al. (2003), Rostrup-Nielsen (2001), and Farmanov et al. (2020), were used as the documentary basis for the synthesis of the findings presented below [4].

## 3. Results

The literature analysis showed that coal, natural gas and light hydrocarbons, petroleum products, biomass, and water are among the principal raw materials and sources used for synthesis gas and hydrogen production.

Natural gas and light hydrocarbons can be processed through steam reforming, partial oxidation, autothermal reforming, and plasma-catalytic reforming. Petroleum products can be converted through dehydrocyclization and aromatization, oxidative steam reforming, and pyrolytic decomposition. Biomass can be processed by gasification, steam reforming, and biological conversion, while water can serve as a source of hydrogen through electrolysis, photocatalytic, chemical, and catalytic conversion.

The reviewed information also indicates that synthesis gas is an important feedstock for methanol production and Fischer–Tropsch synthesis. Methanol is used as a fuel and octane-boosting additive and as a feedstock for the production of formaldehyde, dimethyl ether, methyl tert-butyl ether, acetic acid, and olefins.

In Fischer–Tropsch processing, synthesis gas can be converted into alpha-olefins and paraffins, predominantly linear hydrocarbons, covering a broad carbon-number range [5]. Oxygenated compounds such as alcohols, aldehydes, ketones, and carboxylic acids can also be formed.[6]

The supplied manuscript reports that ammonia production is a major consumer of hydrogen, while significant quantities are also used in oil refining and methanol production. In gas-processing and refining operations, hydrogen is used for hydrotreating, hydrocracking, and other

hydrogenation processes.[7].

## 4. Discussion

The reviewed literature demonstrates that the industrial value of synthesis gas and hydrogen is closely connected with both energy production and chemical synthesis. The selection of a production route depends on the nature of the feedstock, the required product composition, process conditions, and catalyst performance.[8]

Steam reforming of hydrocarbon feedstock is particularly important because it provides synthesis gas suitable for subsequent CO- and $H_2$-based synthesis processes. [9] However, the severe operating conditions make catalyst stability a critical issue. [10] Carbon deposition can block active sites and reduce catalyst activity, while sulfur-containing compounds can poison nickel active sites through the formation of inactive metal sulfides.[11]

These factors explain the importance of catalyst supports and catalyst formulations with high thermal and chemical stability, adequate mechanical strength, and resistance to coke formation and sulfur compounds.[12] The reviewed material therefore indicates that further development of reforming catalysts should focus not only on activity and selectivity but also on resistance to deactivation under realistic hydrocarbon-feed conditions.[13]

The industrial utilization pathways discussed in the manuscript also show that improvements in synthesis-gas production can influence several downstream sectors, including methanol production, Fischer–Tropsch synthesis, ammonia production, and petroleum refining.[14] Thus, catalyst durability and feedstock tolerance are important technological considerations for the broader chemical utilization of synthesis gas and hydrogen.[15]

## 5. Conclusion

A review of the literature indicates that steam reforming of hydrocarbon feedstock is an important and economically significant method for producing hydrogen and synthesis gas for CO- and $H_2$-based synthesis processes. The operating conditions during steam reforming impose stringent requirements on catalysts and their supports.

The analysis of the supplied scientific and technical literature shows that resistance to coke formation and hydrogen sulfide impurities is a key characteristic of catalysts used in the steam reforming of natural gas. Synthesis gas and hydrogen also have broad applications in methanol production, Fischer–Tropsch synthesis, ammonia production, and petroleum refining.

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