

Catalytic Processes for Utilization of Hydrogen Carriers

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1. Energy carriers

For the development of carbon-free energy, hydrogen is considered as promising fuel. For the storage and transportation of hydrogen, however, several compounds have been investigated as candidates of energy carriers, e.g., liquid hydrogen, methane, methyl cyclohexane, and ammonia. In the future, these carrier compounds will be produced by renewable energy sources, such as solar heat and power, wind power, and hydropower. Then the carrier is transported to energy consumption sites. Most of production of hydrogen carriers and recovery of hydrogen involve catalytic processes [1]. Hydrogen is produced by steam reforming of hydrocarbons. By using renewable energy, electrolysis of water or steam is considered as the candidate. Catalytic Sabatier reaction has been known as production process of methane from CO₂ and hydrogen. Hydrogenation of toluene is the well-established catalytic process, whereas catalytic dehydrogenation of methyl cyclohexane has been developed recently. [2] The amount of synthetic ammonia exceeds 150 million tons per annum by the Haber–Bosch process. This process has been a well-established technology for ammonia synthesis from its invention in 1906 using doubly promoted iron as a catalyst. A Ru-based ammonia synthesis catalyst is known to be more active than Fe-based catalysts. [3] Recently, Ru-loaded electrone [Ca₂₄Al₂₈O₆₄]⁴⁺(e⁻)₄ or other supported Ru catalysts were reported to be active. [4] Although ammonia has not been synthesized or used as an energy carrier or fuel so far, this has been attracting attention as an energy carrier. Clearly, the catalysts are key in the production and utilization of ammonia fuel.

2. Utilization of energy carriers

For conversion of energy carriers to electricity, combustion of hydrogen, methane, and ammonia has been investigated. Another process is to recover hydrogen to be connected to the supply chain such as hydrogen stations. Another method is to supply the carrier compound to fuel cells directly. In the case of ammonia and methane the efficiency can be enhanced when endothermic decomposition or reforming is coupled with high temperature exothermic electrochemical oxidation of solid oxide fuel cells (SOFCs). In the case of methane, coupling of reforming and SOFC has been known as internal reforming SOFC which has been adopted in many systems. Direct supply of ammonia to a fuel cell was possible leading to a simplified system with high-efficiency generation. Operation temperature of SOFC 700-900°C sufficiently high for NH₃ decomposition. [5] Anode-supported SOFC with a yttria-stabilized zirconia electrolyte was successfully operated by direct supply of ammonia to the cell. The planar SOFC stack consisting of 10 single cells attained the maximum power of 255 W.

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