Development of Catalytic Reactors and Solid Oxide Fuel Cells Systems for Utilization of Ammonia

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Hydrogen carrier & energy conversion technology

- Ammonia as a promising hydrogen carrier:
  - **High H₂ density, Carbon-free, Low production cost, High boiling point, Ease in liquefaction and transportation, etc.**

<table>
<thead>
<tr>
<th>Ammonia &amp; Fuels</th>
<th>H₂ density (kg-H₂ / m³-liq.)</th>
<th>Boiling point (°C)</th>
<th>ΔHₗ (kJ/mol-H₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid H₂</td>
<td>70.8</td>
<td>–252.6</td>
<td>–</td>
</tr>
<tr>
<td>NH₃</td>
<td>120.3</td>
<td>–33.3</td>
<td>30.6</td>
</tr>
<tr>
<td>2NH₃ → N₂ + 3H₂</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>C₇H₁₄ (Methylcyclohexane)</td>
<td>47.1</td>
<td>101.1</td>
<td>80.0</td>
</tr>
<tr>
<td>C₇H₁₄ → C₇H₈ + 3H₂</td>
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![Operating temperature ranges of fuel cells and catalytic reformers](image)

**Fig.** Operating temperature ranges of fuel cells and catalytic reformers

### Fuel cells
- PEFC
- PAFC
- AMFC
- Molten Alkali FC
- SOFC
- MCFC
- MeOH
- Hydrocarbons
- NH₃

### Reforming / decomposition

Temperature (°C)

0 100 200 300 400 500 600 700
Operation type of ammonia fueled SOFC

R: NH₃ decomposition reactor, C: Fuel cell chamber, S: SOFC stack

**External Decomposition**
- NH₃ decomp. reactor installed on the flow line
- Optimized operation of each reactor
- Large energy loss
- Large system size
- Stationary application

**Indirect Internal Decomposition**
- Reactor installed in the FC chamber
- System design with effective heat management
- Either stationary or mobile application

**Direct Internal Decomposition**
- NH₃ decomp. reactor unnecessary
- NH₃ decom. and anode reaction proceed on the electrode
- Simplified system
- Multifunctional electrode
- Heat management
- Either stationary or mobile application
System specification & flow diagram

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<th>Specification</th>
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<tr>
<td>Fuel / Supply</td>
<td>Steady condition Direct Supply of ammonia (100%) without cracker</td>
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<td>Heat output</td>
<td>None (electricity only)</td>
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<td>Output</td>
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<td>Operation</td>
<td>Automatic control</td>
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<td>Start-up</td>
<td>Heating with cathode gas with air preheater</td>
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Design of system

System package CAD model

- **Term**: Fuel / Supply
  - Steady condition Direct Supply of ammonia (100%) without cracker
- **Term**: Heat output
  - None (electricity only)
- **Term**: Output
  - DC (without inverter)
- **Term**: Operation
  - Automatic control
- **Term**: Start-up
  - Heating with cathode gas with air preheater

[Diagram of system package CAD model]

- **BOP**: MFC, Blower

Electronic load

Hot module

Temperature [K]

- **NH₃**, **H₂**, **N₂**
- **DC 1 kW**
- **Power**
- **Controller**
- **Exhaust**
- **Air**
- **Blower**
- **MFC**
- **Heater**

[Diagram of system package CAD model]
Summary

Ammonia-fueled SOFC stack with 1 kW power output has been successfully operated and high DC efficiency over 50% LHV.

Stability of the stack has been improved by introducing ammonia pre-cracking catalyst and surface treatment of metal separators.

Automated 1 kW-class SOFC package has been successfully operated.

Auto-thermal ammonia cracker has been developed for start-up of the SOFC systems.

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