Hydrogen Production by Nuclear Power

Practical Pathways for Gradual Realization

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Need for Hydrogen in Non-Electricity Energy Sectors

Global energy-related CO2 emission by sector

- Power industry: 38%
- Other industrial combustion: 21%
- Transportation: 20%
- Buildings: 9%
- Other sectors: 12%

Total 37.9 Billion Ton

CO2 emission reduction through the use of hydrogen in industrial and transportation sectors

- Energy storage and feedstock synthetic fuels
- Fuel cells for heavy duty vehicles and building heating
- Steel production by hydrogen reduction and other uses

Hydrogen production

# Hydrogen Production Methods

<table>
<thead>
<tr>
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<th>Water Electrolysis</th>
<th>Chemical Water Splitting</th>
<th>5. Steam Methane Reforming (SMR)</th>
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</thead>
<tbody>
<tr>
<td><strong>Operating Temperature</strong></td>
<td>60~90 °C</td>
<td>Over 700 °C</td>
<td>Over 700 °C</td>
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<td><strong>Features</strong></td>
<td>High pressure</td>
<td>High energy use</td>
<td>Proven technology</td>
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<td>High current density</td>
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<td>High gas purity</td>
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<td></td>
<td>Flexibility</td>
<td>High efficiency</td>
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<td></td>
<td>Expensive catalyst</td>
<td>Closed system</td>
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<td></td>
<td>High cost</td>
<td>Continuous production</td>
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<td></td>
<td>Low pressure</td>
<td>Corrosive environment</td>
<td>× Highest CO₂ emission</td>
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<td>Low flexibility</td>
<td>Cheap catalyst</td>
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<td>Low gas purity</td>
<td>Heat energy use</td>
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<td>Corrosive electrolyte</td>
<td>Heat efficiency</td>
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Limitation of Renewables Due to Low Capacity Factors

Korea Case

- Intermittent and variable electricity input causes instability in electrolyzer
- Low capacity factor leads to higher electricity cost and electrolyzer cost

* Internal calculation by KAERI based on two assumed values of CAPEX and electricity price.
Advantage of High Temperature Steam Electrolysis with Nuclear Power

Energy demand as a function of temperature for electrolysis

SOEC: Solid Oxide Electrolysis
LWR: Light Water Reactor
HTGR: High Temperature Gas Cooled Reactor
Status of High Temperature Steam Electrolysis with Nuclear Power

- 100 kW Bloom energy HTSE system is being operated at INL
- Xcel Energy will install a 100+ kW HTSE system at an NPP in the Minneapolis/St. Paul region
- APS is evaluating the integration of a HTSE system at its Palo Verde Nuclear Generating Station

*Arizona Public Services

Overview of HTSE integrated with an NPP
Source: INL, 2022

Bloom prototype 100 kW HTE system at INL
Source: INL, 2022

The Prairie Island nuclear power plant
(Photo: Xcel Energy)
High Temperature Gas Reactors

Technical characteristics

- Heat supply capability (550~900°C)
- Safety features (TRISO coated fuel)
- Technical maturity
- Nuclear non-proliferation and security

Potential benefits

- Low carbon energy source
- High-temperature heat supply
- Reliability and flexibility

Source: Gougar, H.D., INL, 2019
Better Possibilities with High Temperature Gas Reactors

### Steam Methane Reforming with Carbon Capture and Sequestration

$\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2$ (206 kJ/mol)

$\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2\text{O}$

### High Temperature Steam Electrolysis with SOEC

Challenges in Sulfur-Iodine Chemical Cycle even with the Availability of High Temperature Heat

HIx Section (a mixture of iodine and iodides)

- A large thermal burden (decrease of the global efficiency) due to azeotropic composition in the HI/H2O system (at about 57% w/w)
- Excess of water and iodine from Bunsen reaction
- Electrodialysis (ED) was proposed to concentrate HI aqueous solutions.
- The ED system is still having a high electricity consumption.

HIx from Bunsen

Electrodialysis (ED) was proposed to concentrate HI aqueous solutions.
Practical Pathways for Nuclear Hydrogen Production

- Alkaline Electrolysis with Operating Nuclear Reactors
- High Temperature Steam Electrolysis with Operating and Newly Built Reactors
- Steam Methane Reforming with High Temperature Gas Reactors
- HTSE with HTGR
- Chemical Splitting with HTGR
Thank You