Initiatives of HS Division

September 5, 2023

Kozo Takahashi
General Manager, HS Division
Toray Industries, Inc.
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HS division
- Greenerity (Germany)
- Yamanashi Hydrogen Company (YHC)

Board of Directors
- Chairman
- President
- Vice President

The Executive Committee meeting

Business Planning Division

Affiliated Companies Division

Quality Assurance Division

Technology Center
- New Projects Development Division
- Advanced Materials & Application Technology Center Planning Division

Research & Development Division

Engineering Division
- Advanced Materials & Application Center
- Technology Center Planning Division

Manufacturing Division
- Production-related Departments
- Technology-related Departments

Technology-related Departments

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## History Leading to the Establishment of HS Division

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tr>
<td>2012</td>
<td>Research &amp; Development Division (Advanced Material Research Laboratory)</td>
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<tr>
<td>2014</td>
<td>Establishment of Greenerity (Acquired SolviCore)</td>
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<tr>
<td>2016</td>
<td>Establishment of basic concept of hydrocarbon (HC) electrolyte membrane (laboratory)</td>
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<tr>
<td>2018</td>
<td>Yamanashi P2G Demonstration Project</td>
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<td>2020</td>
<td>HS Division (June 2022)</td>
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<td>2022</td>
<td>Partnership between Siemens Energy and Toray</td>
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</table>

- **Research & Development Division (Advanced Material Research Laboratory)**
- **Establishment of Greenerity (Acquired SolviCore)**
- **Establishment of basic concept of hydrocarbon (HC) electrolyte membrane (laboratory)**
- **Yamanashi P2G Demonstration Project**
- **Green Innovation (GI) Funding Project**
- **Establishment of YHC**
- **Press conference of Toray and Siemens Energy**
Products of HS Division

Production and sales of electrolyte membrane, CCM, and MEA that are key components of water electrolyzer, hydrogen compressor, and fuel cell

- Electrolyte Membrane, CCM
- CP
- Carbon Fiber for high-pressure tanks
- Plastic Liner

- Hydrogen Refueling Station
- Hydrogen Tank

- Hydrogen
- Fuel cell vehicles
- Factories, Supermarkets

Production and sales of electrolyte membrane, CCM, and MEA

- Electrolyte Membrane
- CCM
- MEA

Toray Group products

Use

Transportation & storage

Production

Renewable energy power from wind power, solar power, etc.

- Water Electrolyzer
- Hydrogen Compressor
- Hydrogen Refueling Station
- Hydrogen Tank

- Hydrogen

- Fuel cell vehicles
- Factories, Supermarkets

CCM: Catalyst Coated Membrane

MEA: Membrane Electrode Assembly

GDL: Gas Diffusion Layer

CP: Carbon Paper

Catalyst layer
Toray’s Hydrocarbon (HC) Electrolyte Membrane and Initiatives for Water Electrolysis Application
# Applications of Electrolyte Membrane

<table>
<thead>
<tr>
<th></th>
<th>Production</th>
<th>Transportation &amp; Storage</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water electrolysis</strong></td>
<td><img src="Diagram1.png" alt="Diagram" /></td>
<td><img src="Diagram2.png" alt="Diagram" /></td>
<td><img src="Diagram3.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Structure</td>
<td><img src="Diagram1.png" alt="Diagram" /></td>
<td><img src="Diagram2.png" alt="Diagram" /></td>
<td><img src="Diagram3.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Principle</td>
<td>Produce hydrogen from water by electricity</td>
<td>Compress hydrogen by electricity</td>
<td>Power generation using hydrogen and air</td>
</tr>
<tr>
<td></td>
<td>( \text{H}_2\text{O} \rightarrow \text{H}_2 + \frac{1}{2} \text{O}_2 )</td>
<td>( \text{H}_2 ) (0.1MPa) ( \rightarrow ) ( \text{H}_2 ) (80MPa)</td>
<td>( \text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{O} )</td>
</tr>
<tr>
<td>Value of HC electrolyte membrane</td>
<td>Highly efficient hydrogen production, utilizing low gas permeability</td>
<td>High-pressure hydrogen compression, utilizing low gas permeability</td>
<td>High power density by taking advantage of high temperature drivability</td>
</tr>
</tbody>
</table>

Electrolyte membrane is the key material common for water electrolysis, hydrogen compression, and fuel cell.
**Principle of Green Hydrogen Production by Water Electrolysis and Function of Electrolyte Membrane**

**Polymer electrolyte membrane (PEM) water electrolysis**

\[ 2H_2O \rightarrow 2H_2 + O_2 \]

Electrolyte membranes affect the performance of water electrolyzers.

- The higher the hydrogen ion (H+) conductivity, the more hydrogen is produced per electrode area.
- The lower the gas permeability, the less backflow of product gas, and the higher efficiency, operating rate, and safety.

**Equipment Configuration**

- Rectifier
- Solar power
- Wind power
- Oxygen
- Hydrogen
- Water
- Gas-liquid separator
- Stack
- Gas-liquid separator
- Gas Diffusion Layer (GDL), etc.
- Anode catalyst
- Cathode catalyst
- Electrolyte membrane
- Catalyst layer
- CCM (Catalyst coated membrane)

**Basic structure of cells**

- Water
- Separator
- Water
- Gas-liquid separator
- Stack
- Gas-liquid separator
- Gas Diffusion Layer (GDL), etc.
- Anode catalyst
- Cathode catalyst
- Electrolyte membrane
- Catalyst layer
- CCM (Catalyst coated membrane)

**Electrolyte membranes affect the performance of water electrolyzers**
HC electrolyte membrane is the outcome of Toray’s proprietary polymer design, precise polymerization technology, and nano-level structure control technology.

**Characteristics of “HC electrolyte membrane”**

- **High proton conductivity**: (2-fold)
- **Low gas permeability**: (1/3)
- **High strength**: (4-fold)
- **Heat-resisting property >150°C**: (+60°C)

In comparison to conventional membranes
Value of “HC Electrolyte Membrane”

Expected to contribute to significant reduction of green hydrogen costs by dramatically increasing the efficiency of water electrolysis.

Evaluation results of prototype

- Double amount of hydrogen generated
- "HC Electrolyte Membrane"

Current density (A/cm²) vs. Applied voltage (V)

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Standard fluorine membrane</th>
<th>Toray’s HC Electrolyte Membrane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency %</td>
<td>76</td>
<td>87</td>
</tr>
<tr>
<td>High current density A/cm²</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Low gas permeability a.u.</td>
<td>1</td>
<td>1/3</td>
</tr>
</tbody>
</table>

High efficiency
Reduction of stack cost
High safety, high operating rate
Value of “HC Electrolyte Membrane”

Confirmed high followability performance for considerably fluctuating power loads (response and followability)

Results of load response and followability test at NEDO P2G demonstration project (25kW stack)

Expected to contribute to cost reduction, improvement of operation rate, and improvement of adaptability to renewable energy sources of water electrolyzer

Image of the demonstration site in Komekurayama, Yamanashi prefecture

Supplying electricity generated by solar power

Added-value 1
Allow load-following operations in correspondence to renewable energy fluctuations
Value of “HC Electrolysis Membrane”

At low load, generated gas flows back and mixes ⇒ Operation stops

Characteristics of PEM type
Electrolyte membrane prevents backflow of gas, minimum load line is low and restart is quick

Characteristics of HC Electrolysis Membrane
With low gas permeability, there is little gas backflow, leading to lower minimum load line and higher operating rate

Image of the demonstration site in Yonekurayama, Yamanashi prefecture
Supplying electricity generated by solar power

This graph is created by Toray, in reference to materials from IRENA, etc.

Expected to contribute to cost reduction, improvement of operation rate, and improvement of adaptability to renewable energy sources of water electrolyzer
Features of “HC electrolyte membranes” which are expected to contribute to cost reduction:

- Low gas permeability
- High-current density operation
- Highly efficient operation
Japan’s First P2G Company, Yamanashi Hydrogen Company (YHC)

YHC will work on the following:
- Business on hydrogen production, supply, sales and energy services
- Technology development and demonstration on hydrogen production, storage, and transportation
- Business on spreading and expanding hydrogen utilization

< Aim of Establishment >
- Propose solution for “hydrogen production by water electrolysis” to customers
- Develop a framework for hydrogen energy service business in the future
- Keep up-to-date on technologies and trends by implementing up to final stage of the operation

Established in February 2022

YHC
Yamanashi Hydrogen Company, Inc.
Examples Of Development and Demonstrations through National Projects and Partnerships

1.5MW

Commissioned Project by NEDO

Yamanashi Pref. Public Government Enterprise Bureau
Tokyo Electric Power Company Holdings, Inc. (Cooperating with Hitachi Zosen Corporation)

Over 10MW (currently implementing or planning)

Suntory Minami Alps Hakushu Water Plant
Suntory Hakushu Distillery

Green Innovation Funding Program
“Energy transition and off-taker application development using Industrial scale P2G system towards carbon neutrality”

Yamanashi Pref. Public Government Enterprise Bureau, Hitachi Zosen Corporation, Siemens Energy (Cooperating with Suntory)

NEDO’s International Demonstration Project
“Hydrogen Technology Demonstration Requirements Conformity Study for Efficient Thermal Operation at Indian Factories”

YHC, Suzuki Motor Corporation

Maruti Suzuki’s Manesar Plant
シーメンス・エナジーと東レパートナーシップを締結
PEM型水電解を用いたグリーン水素製造により、カーボンニュートラル社会実現に貢献

東レ「炭化水素系電解質膜」を実装した、革新的なシーメンス・エナジー水電解装置「Elyzer」を実現し、グローバルなグリーン水素サプライチェーンの構築を目指します。
1. Company name: Greenerity GmbH
2. Established: July 2015
3. Headquarters: Bayern, Germany
4. Production sites: 3 plants in Hanau and Alzenau
5. Number of employees: 190 (as of the end of August 2023)

Leading company of water electrolysis and fuel cell applications

Expansion of facilities for water electrolysis (plan)

Capacity of CCM (GW)
Water electrolyzer equivalent

Scheduled to begin operation in October 2023

Over 10GW
Market Outlook for Water Electrolyzer and Electrolyte Membrane

Water Electrolyzer

- **Alkaline type**
- **PEM type**

<table>
<thead>
<tr>
<th>Year</th>
<th>2022</th>
<th>2025</th>
<th>2030</th>
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</thead>
<tbody>
<tr>
<td>GW</td>
<td></td>
<td></td>
<td>100</td>
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</tbody>
</table>

Billion yen

Electrolyte Membrane

<table>
<thead>
<tr>
<th>Year</th>
<th>2022</th>
<th>2025</th>
<th>2030</th>
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<tbody>
<tr>
<td>Billion yen</td>
<td></td>
<td></td>
<td>200</td>
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</table>

Estimated by Toray
Materials change our lives.

Innovation by Chemistry
Descriptions of predicted business results, projections and business plans contained in this material are based on assumptions and forecasts regarding the future business environment, made at the time of publication.

Information provided in this material does not constitute any guarantee concerning the Toray Group’s future performance.