Development of a New Thermo-chemical and Electrolytic Hybrid Hydrogen Production Process for Sodium Cooled FBR

Status and Future Plan

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Outline

- Background
- Principle of the new hybrid hydrogen production process
- Current status of R&D
- Future plan

Background

- In “Feasibility study on Commercialized Fast Breeder Reactor (FBR) Cycle Systems” of JAEA, a concept of a multi-purpose (Electricity supply, Hydrogen Production, etc.) small sized reactor has been studied.
- Requirements for hydrogen production system of FBR
  - Maximum temperature : 500-550 deg-C
  - Thermal efficiency : higher than water electrolysis
  - Hydrogen production from water : No use of fossil fuel, no CO_2 emission.

Applicability of Hydrogen Production Technologies for FBR Plant

Resource	Method	Proposed Tech.	Present Status	Features & Issues
Water	Electrolysis	・Alkaline Water Electrolysis ・SPEWE* ・HTE*	Commercialized R&D Stage	・Mature Tech. ・Low thermal efficiency (~36% for FBR)
	Thermo-chemical Cycle	・I-S method ・UT-3 method ・W.H. method、etc	R&D Stage	・Higher thermal efficiency (~50%) ・High temperature heat source ・Material corrosion
Fossil Fuels	Steam Reforming	・Steam Reforming of Natural Gas ・SER* Process ・ Membrane Reformer	Commercialized Demonstration Stage	・Excellent thermal efficiency (70%~) ・High plant construction const; SER & MR ・CO_2 emission

SPEWE: Solid Polymer Electrolyte Water Electrolysis, HTE: High Temperature Electrolysis, SER: Sorption Enhanced Reaction

Development of a Lower Temperature Thermochemical Cycle

Principle of HHLT

HHLT (thermo-chemical and electrolytic Hybrid Hydrogen process in Lower Temperature range)

$2H_2O + SO_2$	->	$H_2SO_4 + H_2$	<100 deg-C (electrolysis:0.17v)	[1]
H_2SO_4	->	$H_2O + SO_3$	400 deg-C (thermal decomposition)	[2]
SO_3	->	$SO_2 + 1/2O_2$	500-550 deg-C (electrolysis:0.13v)	[3]

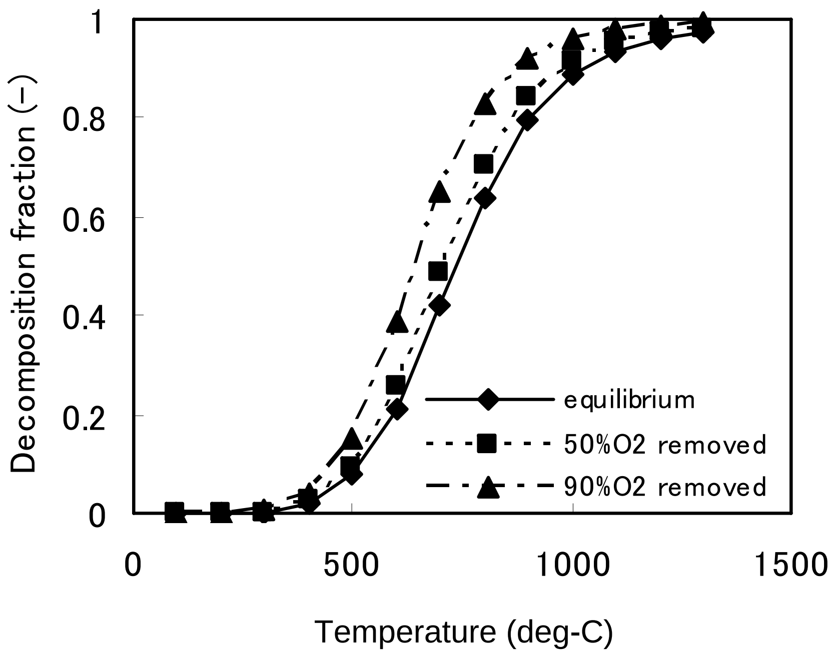
Westinghouse process

SO_3	->	$SO_2 + 1/2O_2$	>800 deg-C (thermal decomposition)	[3]'

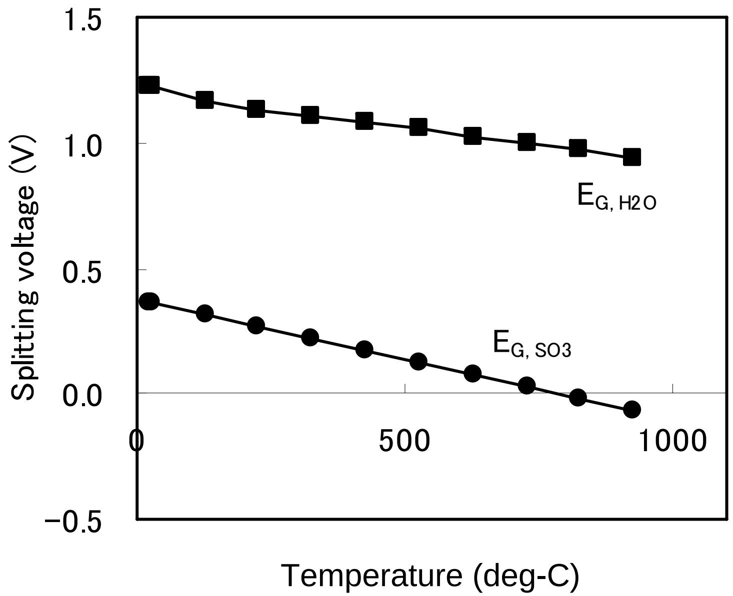
- The hybrid process consists of H_2SO_4 synthesis and decomposition reactions. (Based on “Westinghouse process”)
- Maximum operation temperature is about 500-550 deg-C.
- Hydrogen and oxygen are produced from water.

Electrolytic SO_3 splitting with oxygen conductive solid electrolyte

- **Splitting voltage of SO_3 is 0.13V at 500℃.**

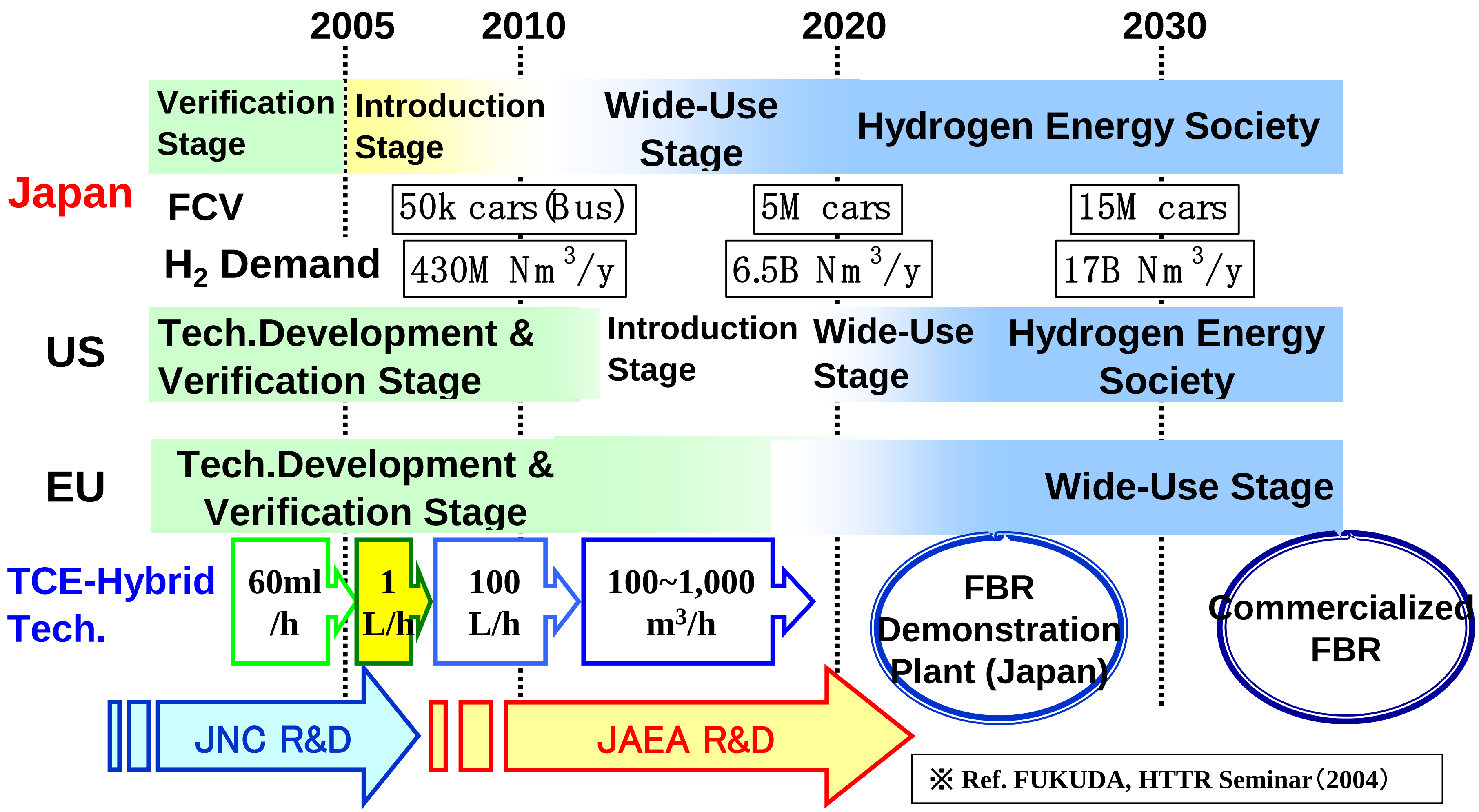


Thermal decomposition fraction of SO_3

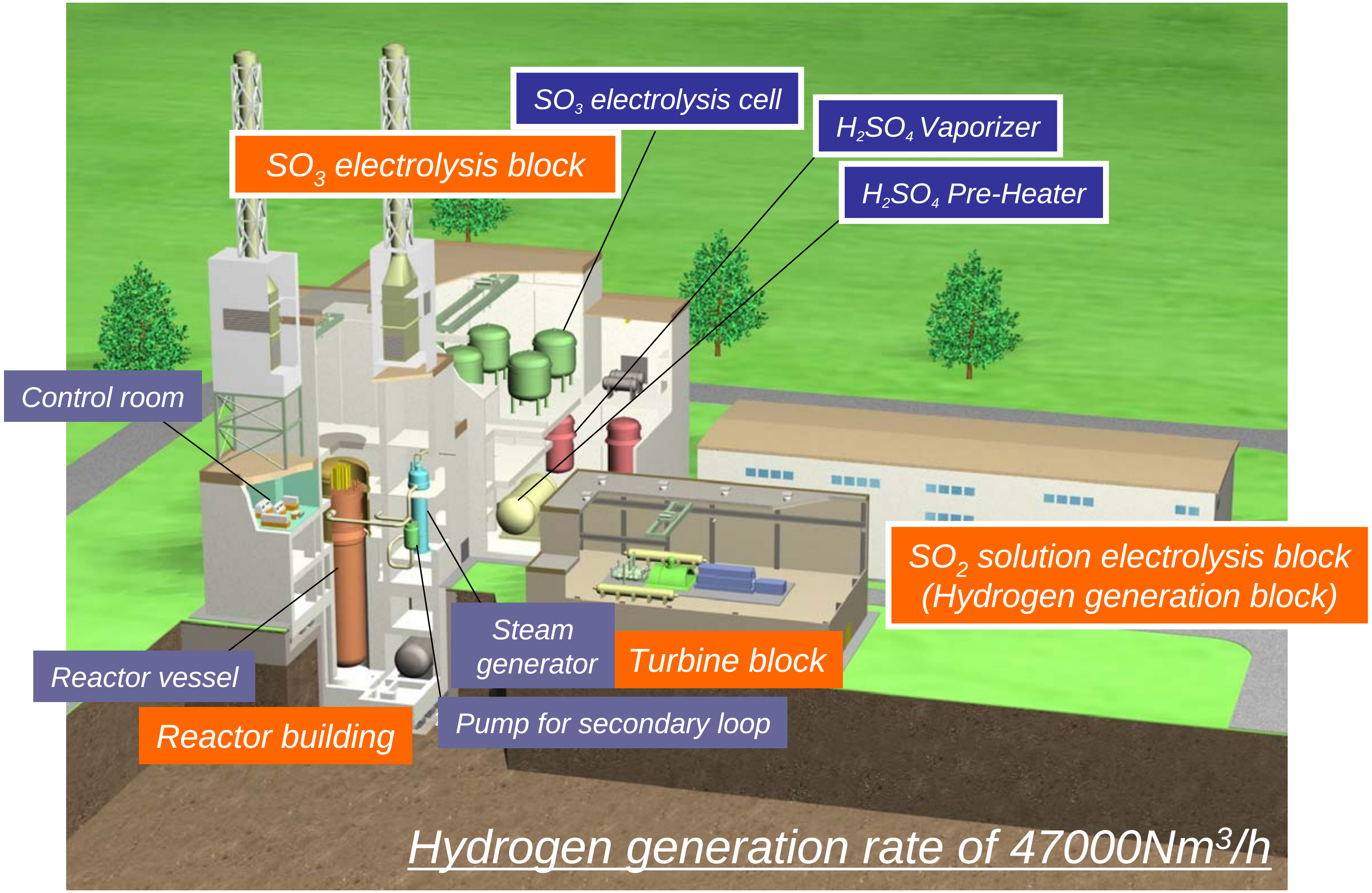


Splitting voltages of H_2O and SO_3

Steps of H_2 Energy Introduction & of Hybrid Tech. Development



Conceptual FBR-Hydrogen Plant Design



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Current status of R&D

- The experimental apparatus for 1NL/h hydrogen production has been developed and an experiment was performed.
  - To evaluate hydrogen production efficiency
  - To extract technical problems to develop 100NL/h-h_2 production apparatus.
- Development of higher performance electrolysis cells and structural materials for H_2SO_4 corrosion have been performed.

Development of the experimental apparatus for 1NL/h hydrogen production

Internal structure of SO_3 electrolysis cell

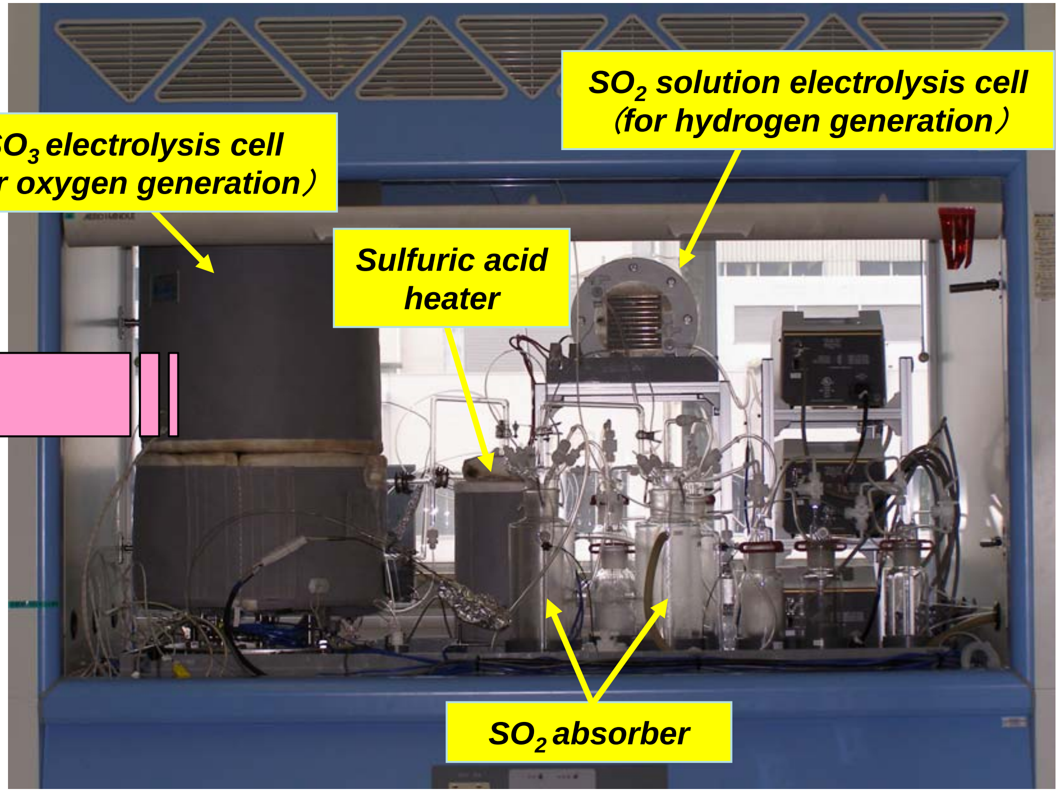

Photo of the experimental apparatus

Experimental apparatus for 1NL/h H_2 production

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Experimental conditions of the hydrogen production experiment

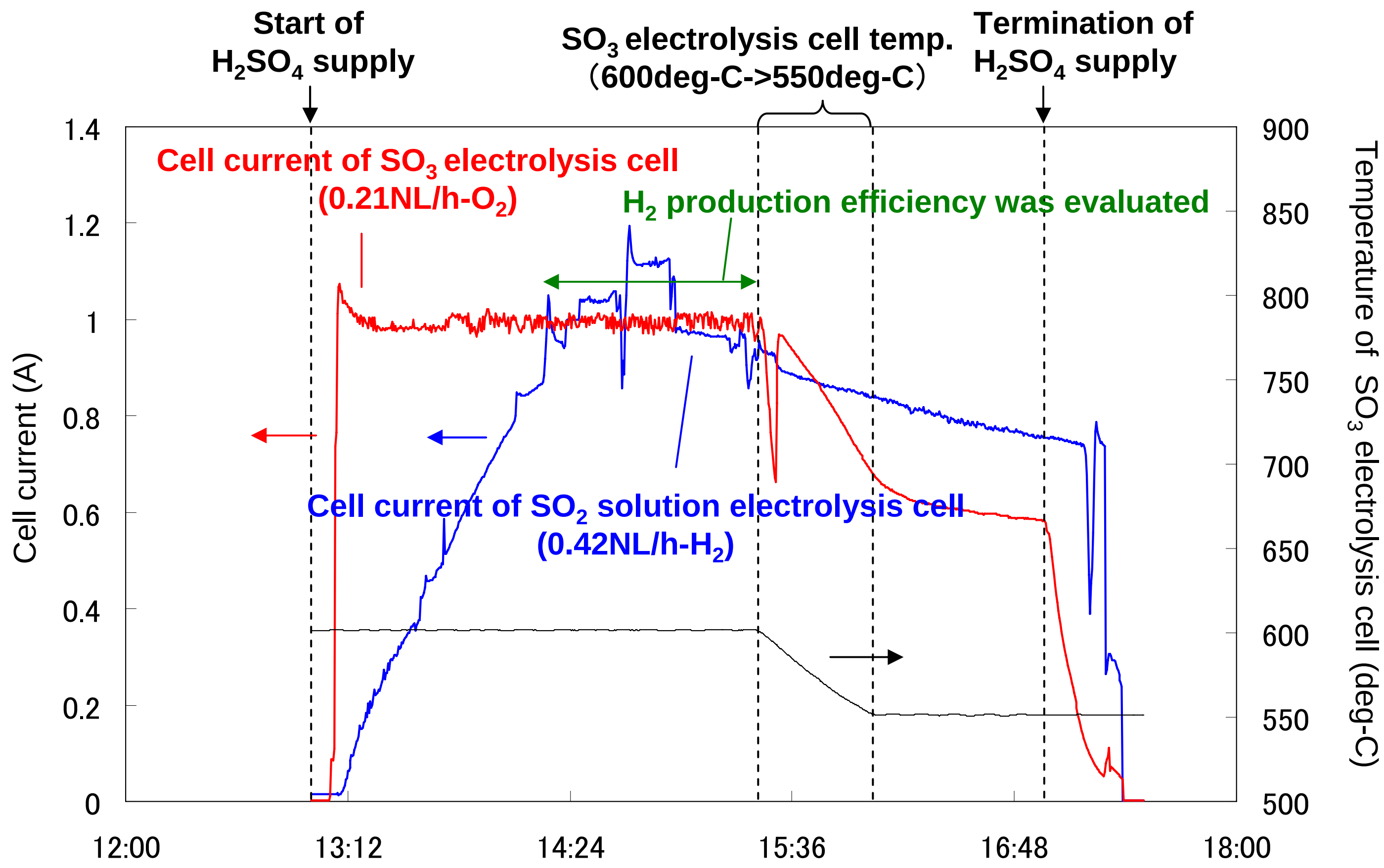
Experimental conditions

Item	Condition
H_2SO_4 vaporizer Temperature	600-700 deg-C
SO_3 electrolysis cell Temperature cell voltage	600 deg-C ->550 deg-C 0.85V
SO_2 solution electrolysis cell Temperature Cell voltage	8 deg-C 1.2V-1.1V
H_2SO_4 concentration H_2SO_4 flow rate	50wt% 2ml/min

Target value

item	condition
H_2 production rate	0.5NL/h (current value:1.2A)
O_2 production rate	0.25NL/h (current value:1.2A)
Experimental duration	1-several hours

Experimental result



Measured cell current in the hydrogen production experiment

-H_2 production rate: 0.42NL/h, O_2 production rate: 0.21NL/h

Evaluated efficiency

$$\eta = \frac{H_{HHV} * Mx}{P+Q} \qquad \textbf{(1)}$$

Mx : amount of generated X gas (mol, X=hydrogen, oxygen)

$$= \frac{\Sigma Ix * f}{96485 * ex}$$

- *Ix* : cell current of X gas (A)
- *f* : data sampling period (20sec)
- *ex* : number of electron (2 for hydrogen molecule, 4 for oxygen molecule)

H_{HHV}: higher heat value of hydrogen (285.8kJ/mol)

P : electricity supplied to both electrolysis cell (kJ)

-measured by potentiostats (SO_3 electrolysis & SO_2 solution electrolysis)

Q : heat from heat source (kJ)

-No heat loss was considered

-equilibrium composition of gas phase was calculated by MALT-II & GEM

Evaluated thermal efficiency was 2.1%.

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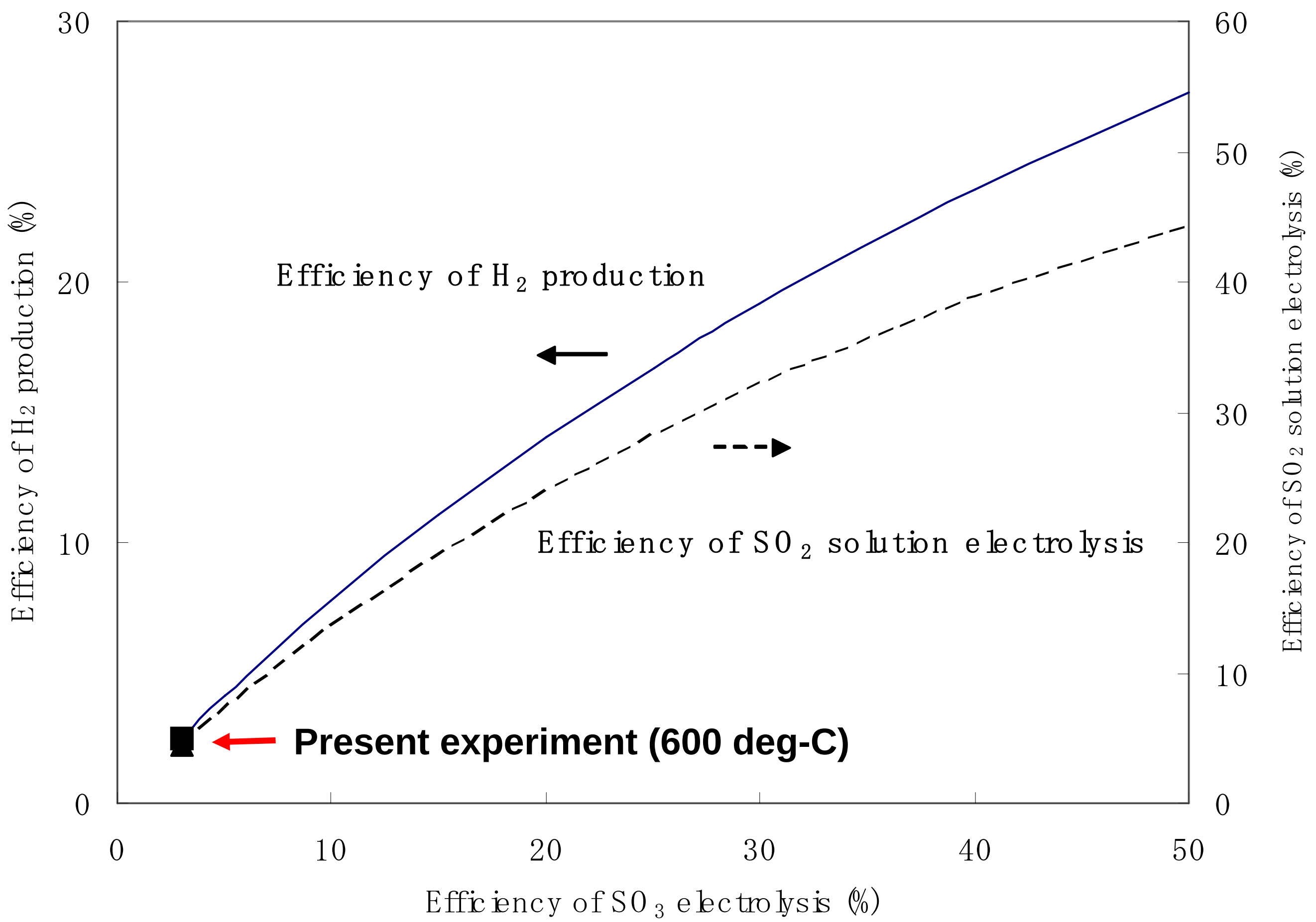
Influence of efficiency of SO_3 electrolysis



Relationship between H_2 production efficiency and SO_3 electrolysis efficiency

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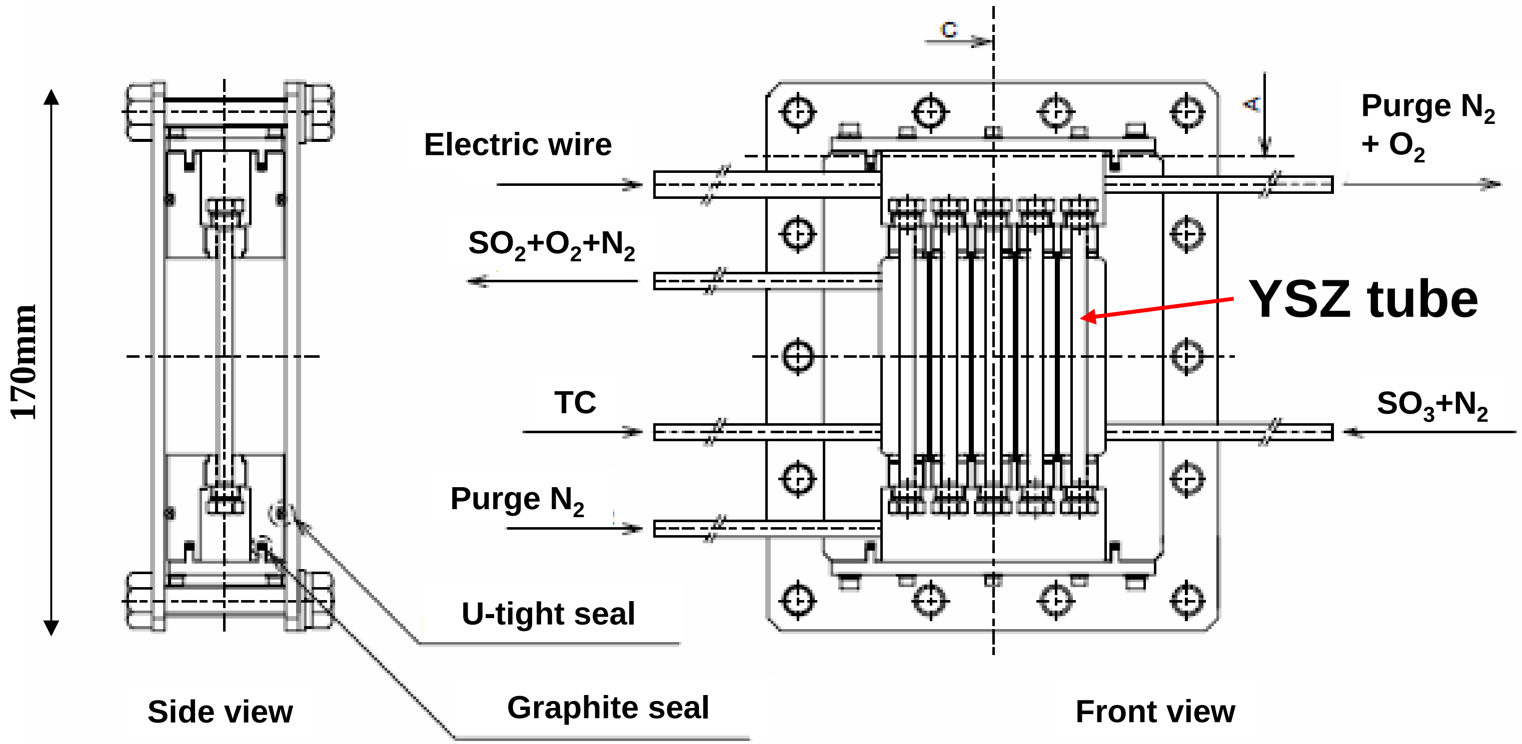
Summary of the hydrogen production experiment

- A hydrogen production experiment was performed using the 1NL/h-h_2 level apparatus.
  - hydrogen production efficiency will be evaluated as about 2%. Efficiency of the electrolysis cells must be increased to obtain higher hydrogen production efficiency.
  - durability of the apparatus must be improved.

Development of SO_3 electrolysis cell

- SO_3 electrolysis cell using small YSZ tube (6mm in diameter, 100mm in length and 0.5mm in thickness) was manufactured.



SO_3 electrolysis cell using small YSZ tube

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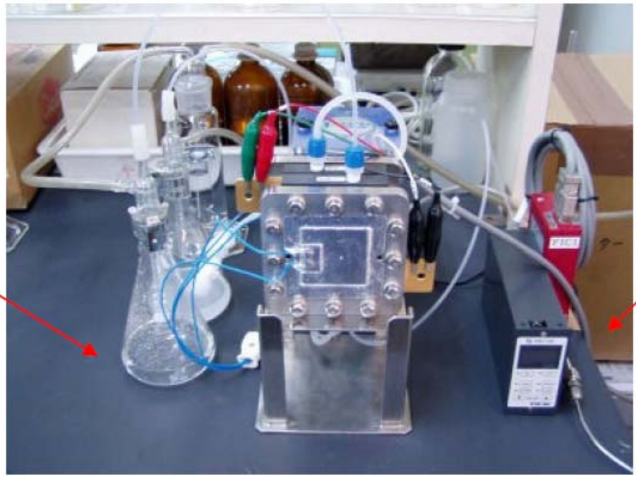
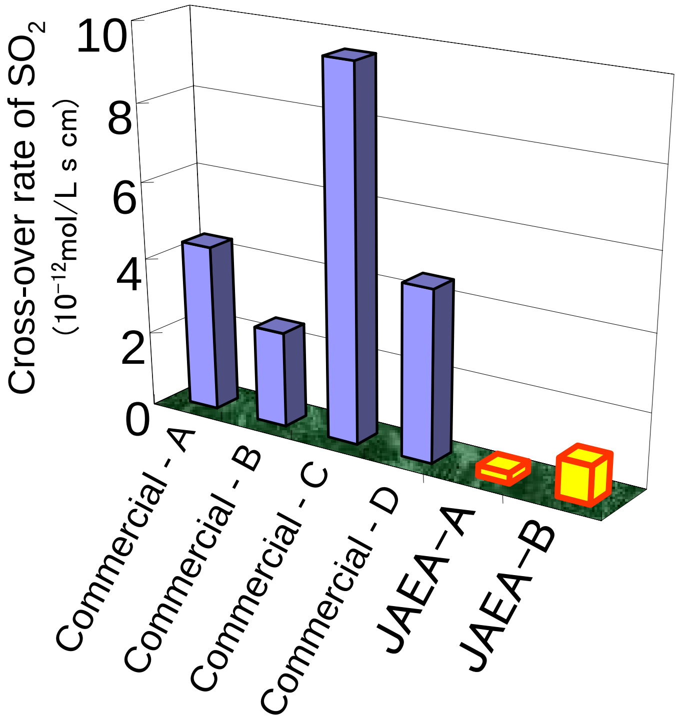
Development of Hydrogen production cell (SO_2 electrolysis)

- PEFC (Polymer Electrolyte Fuel Cell) was modified for hydrogen production supplying SO_2 gas and H_2O.
- Investigation on SO_2 cross-over behavior through some cation exchange membranes has been performed.



Hydrogen production cell
（PEFC base: Electrode area 25cm²）



Cross-over rate of SO_2 through cation membranes

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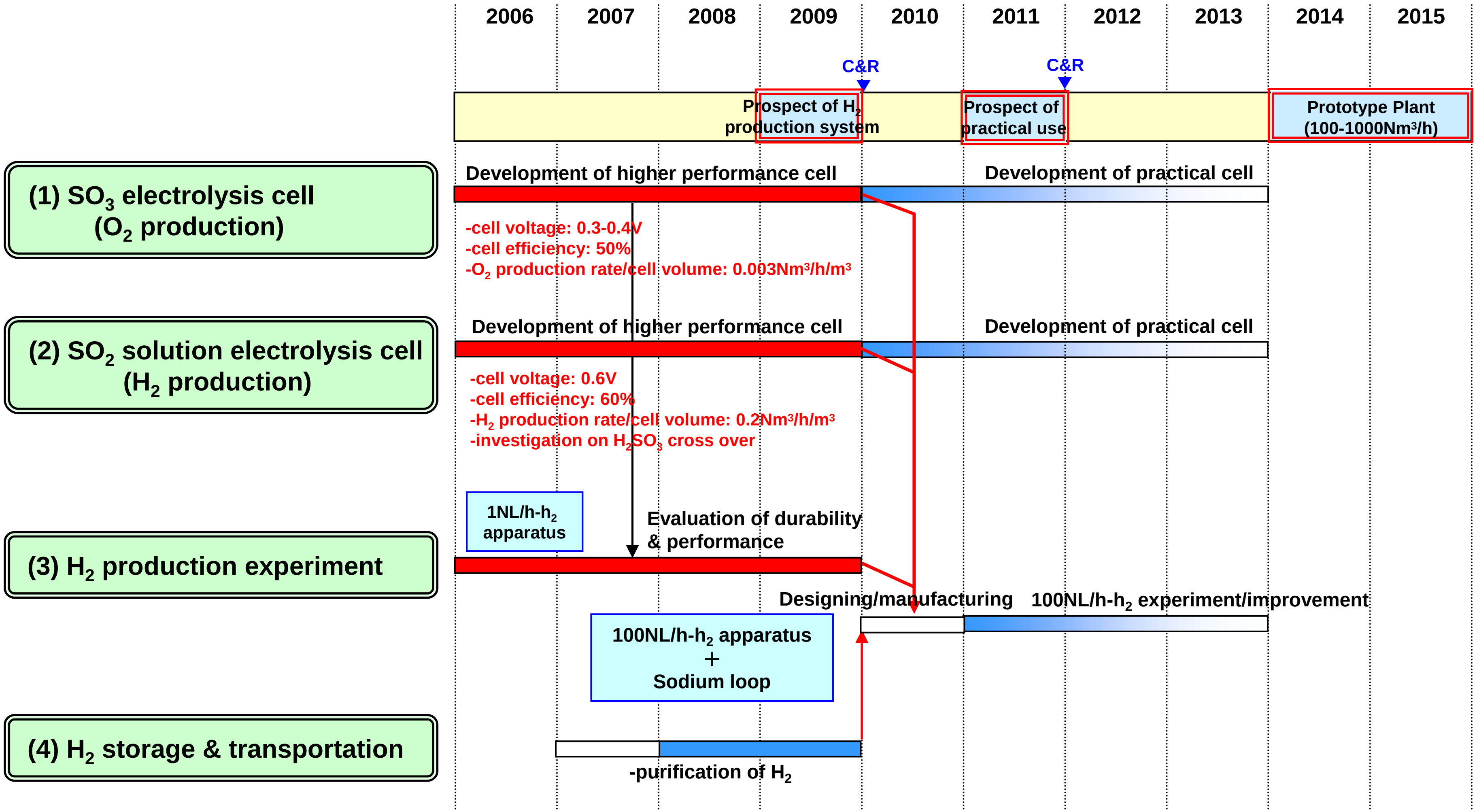
Future Plan



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Conclusion

- The experimental apparatus for 1NL/h-h_2 production by the hybrid sulfur process was developed and technical problems were extracted from the hydrogen production experiment performed in 2006.
- Development of electrolysis cells will be continued for a few years, then development of 100NL/h-h_2 apparatus will be started.