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Development of Nuclear Hydrogen Technologies at Toshiba

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- *Exergy*
- *Hydrogen production*
- *Material*

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Measure of Energy Value

Exergy = $H - H_0 - T_0(S - S_0)$

Exergy ratio =Exergy/($H - H_0$)

Exergy:Effective energy to work

H: Enthalpy

S: Entropy

Exergy Ratio

	Exergy	Exergy ratio
Electricity	Depends on process	**1**
Hydrogen (1 mol production)	237	**0.83**
Biomass (1 mol H2 production)	223	**0.94**
Methane (1 mol H2 production)	205	**0.92**
Heat	Depends on temperature (**0 - 0.55**)	

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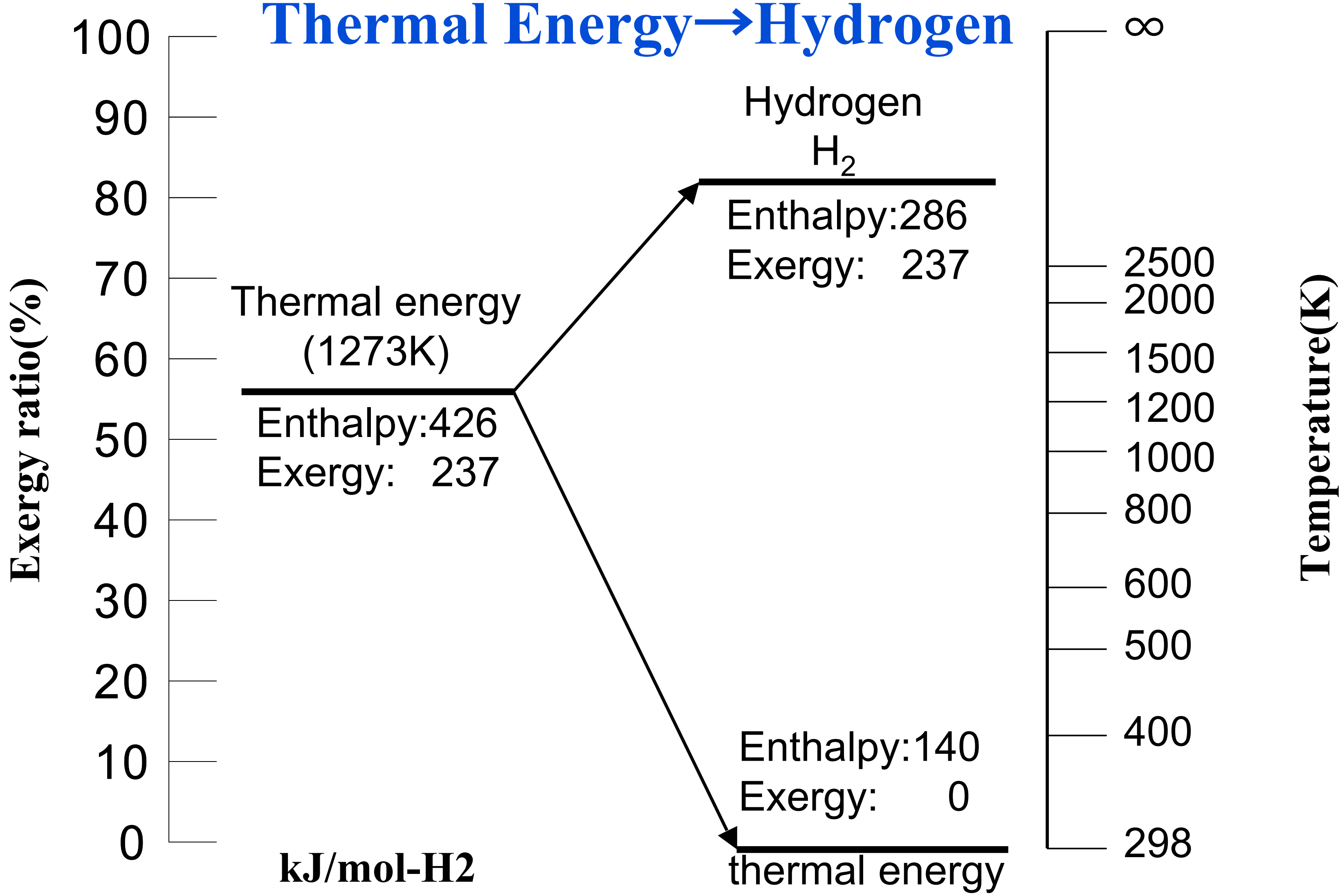
Thermal Energy→Hydrogen



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Why Sulfur Family in thermo chemical process?

Process	**Critical Issues**
Hg family	Existence of Hg
Fe Cl family	Decomposition of Fe Cl_3
Sulfur family	**to be pursed**

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Why SI in Sulfur Family ?

H_2SO_4 >>>> $H_2O + SO_2 + 1/2O_2$

1) SO2 + H2O + ELEC >>>> H2SO4 + H2

2) 2H2O + Br2 + SO2 >>>> H2SO4 + 2HBr

2HBr + ELEC >>>> Br2 + H2

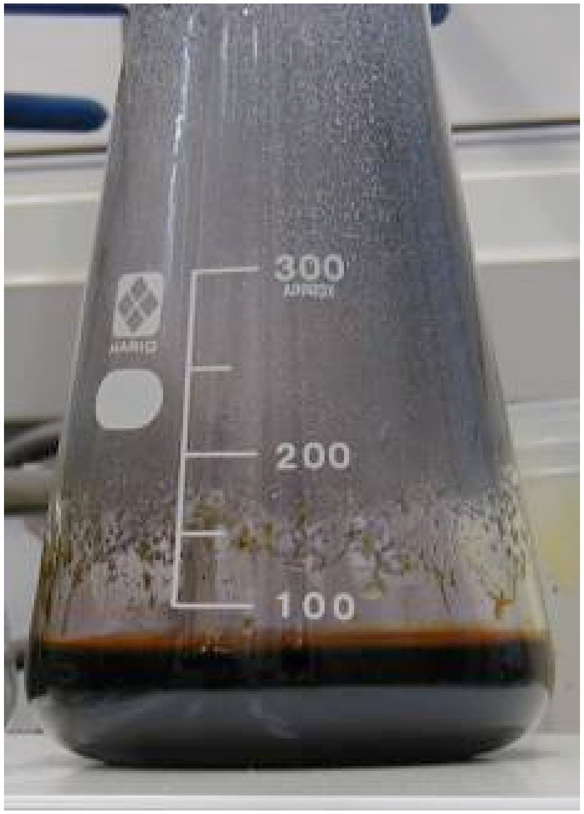
3) $2H_2O + I_2 + SO_2$ >>>> $H_2SO_4 + 2HI$

$2HI$ >>>> $I_2 + H_2$

A rather great deal of R&D in both JAERI and GA

SO_2 gas injection line

SO_2



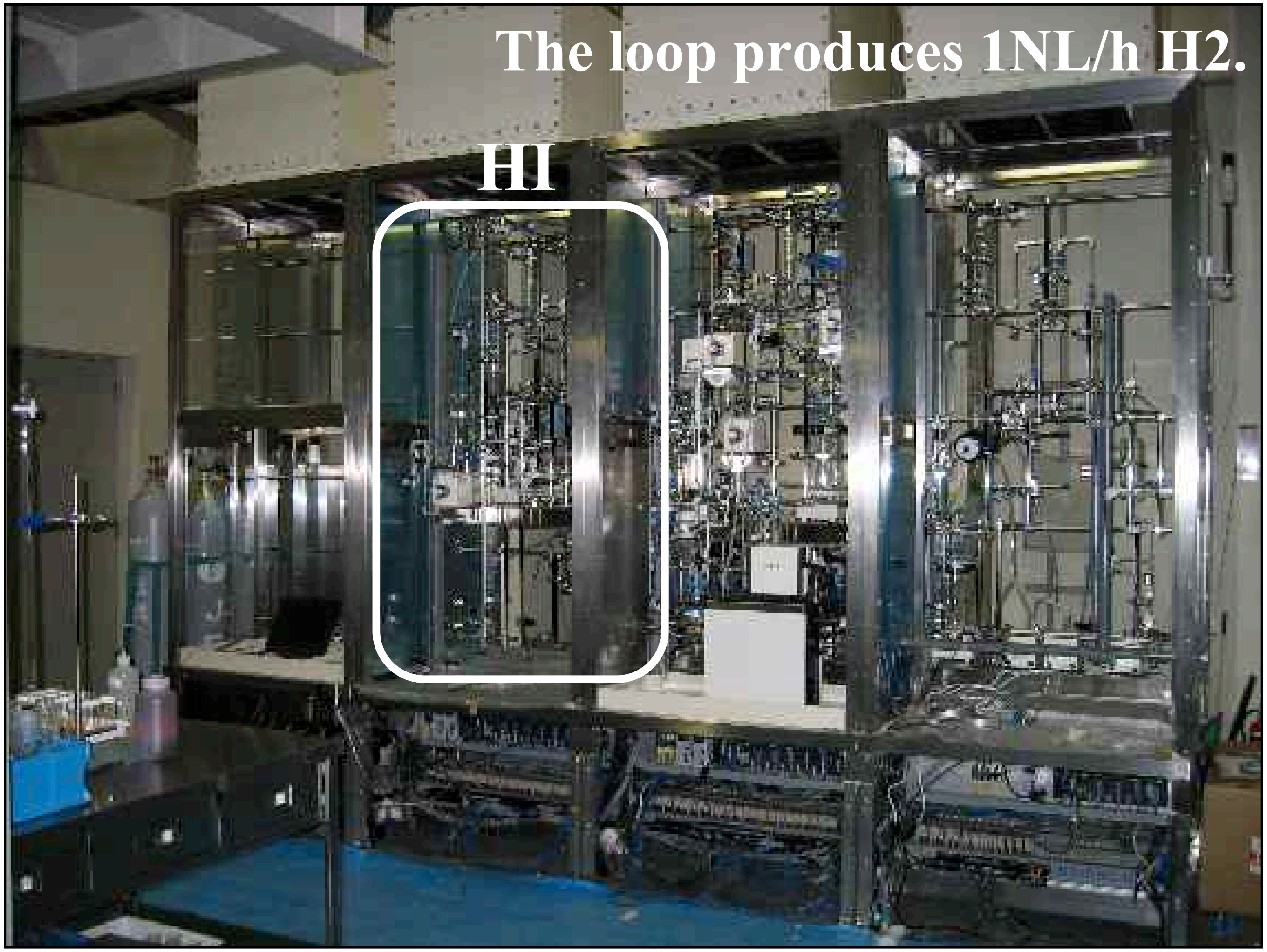
Bunsen Reaction Process

Before After

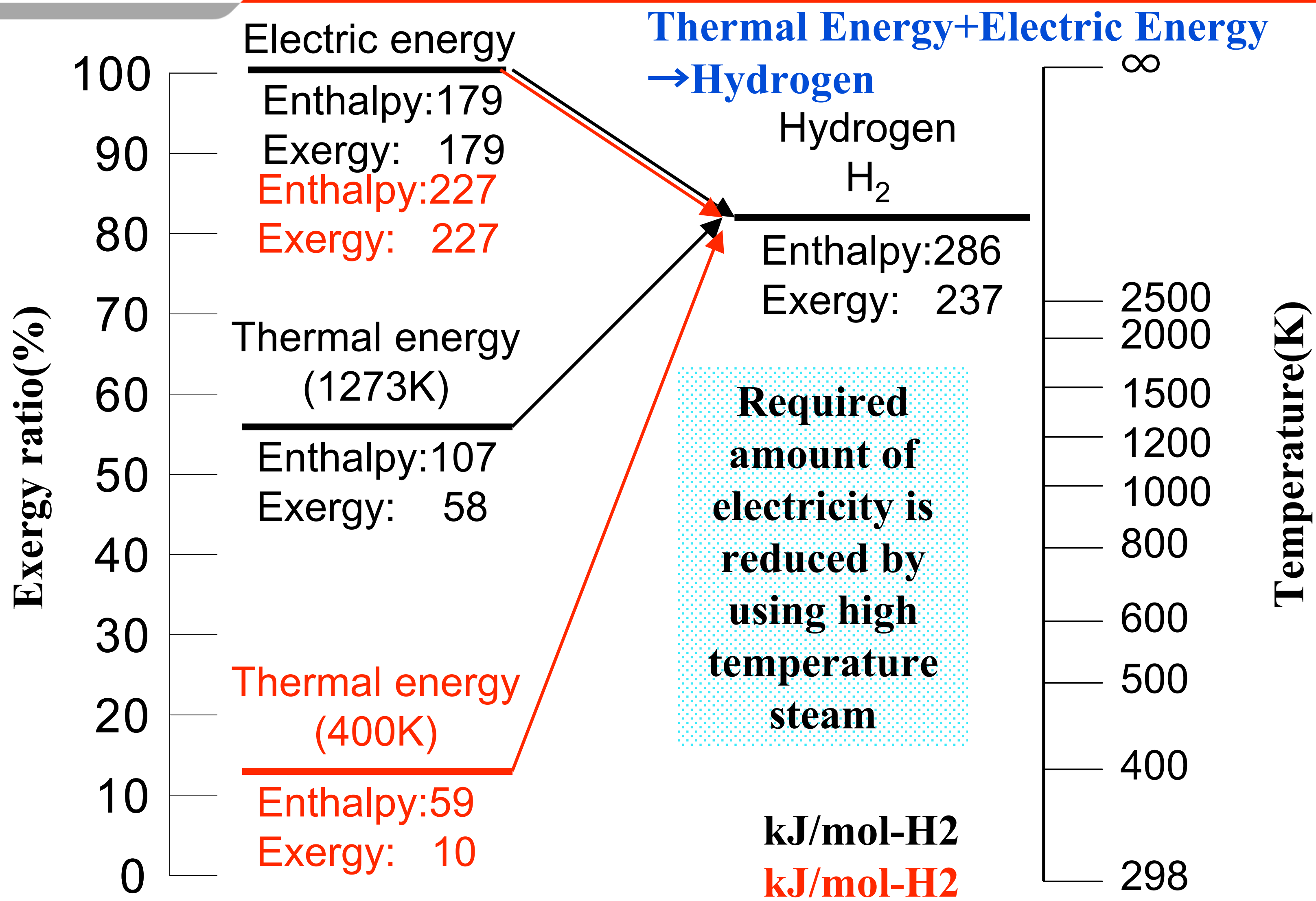
HI concentration

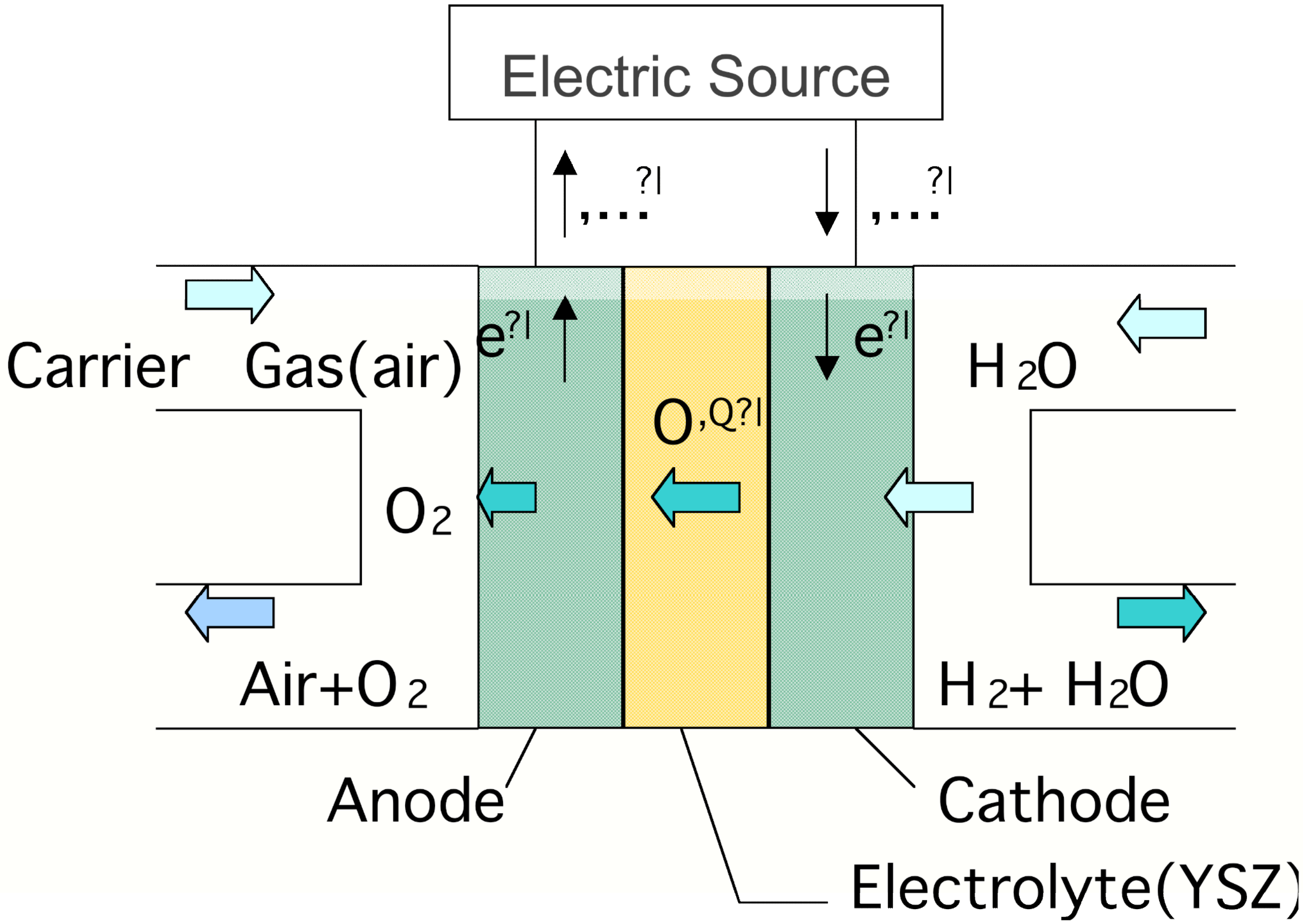
HI gas decomposition apparatus

HI Decomposition Process



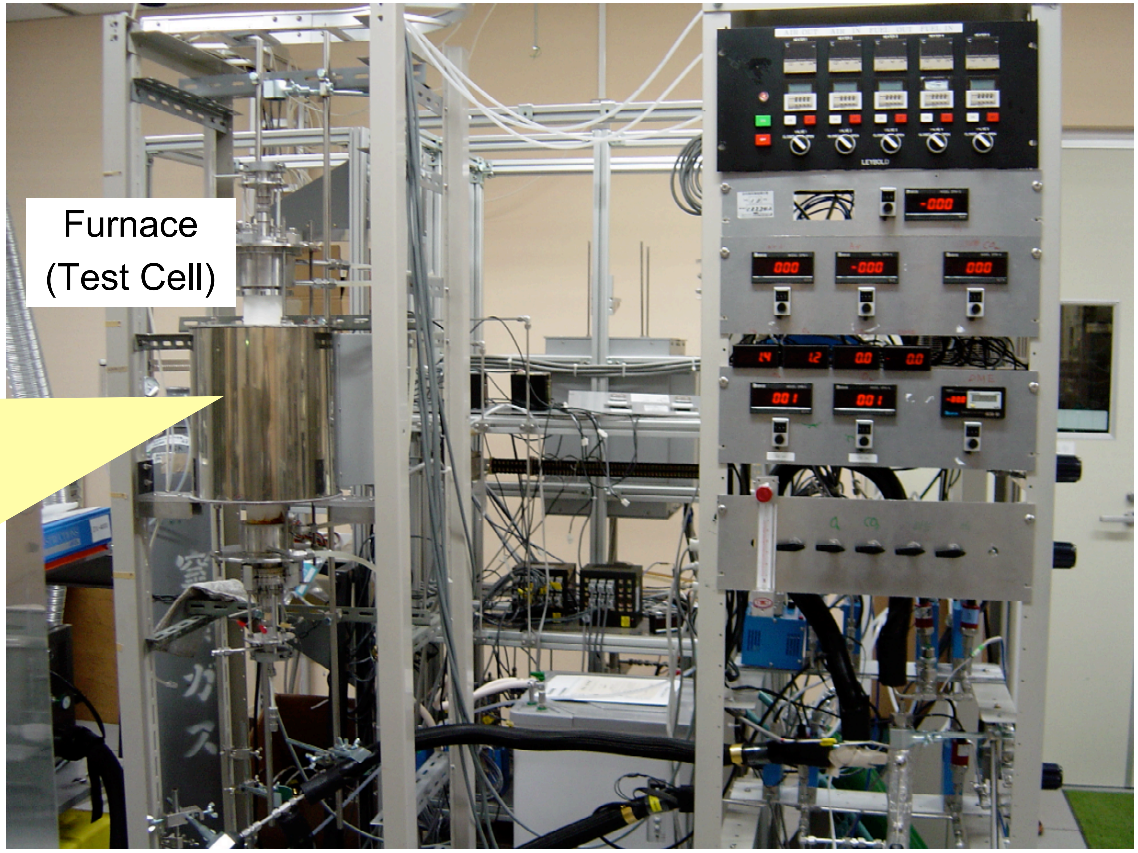
Closed Loop Hydrogen Production Test


Thermal Energy+Electric Energy
→Hydrogen
Electric energy
Enthalpy:179
Exergy: 179
Enthalpy:227
Exergy: 227
Hydrogen
H2
Enthalpy:286
Exergy: 237
Thermal energy
(1273K)
Enthalpy:107
Exergy: 58
Thermal energy
(400K)
Enthalpy:59
Exergy: 10
Required amount of electricity is reduced by using high temperature steam
kJ/mol-H2
kJ/mol-H2
Exergy ratio(%)
100
90
80
70
60
50
40
30
20
10
0
Temperature(K)
∞
2500
2000
1500
1200
1000
800
600
500
400
298



High Temperature Electrolysis

Single tubular cell



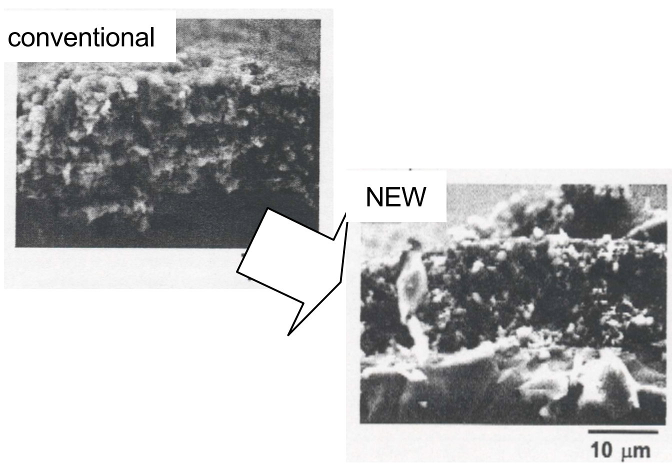
Test rig for HTE tubular cell
(Cooperation with AIST)

Performance Test of HTE Tubular Cell

HTE Electrode

Improvement on Gas-diffusion

Porous electrode

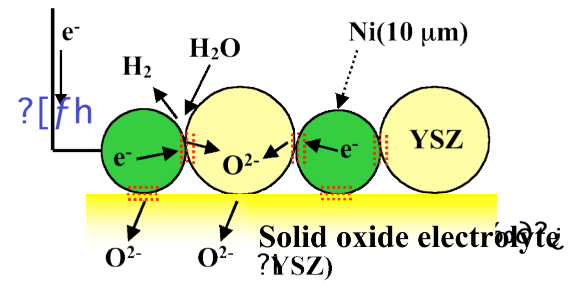


Solid oxide electrolyte (YSZ)

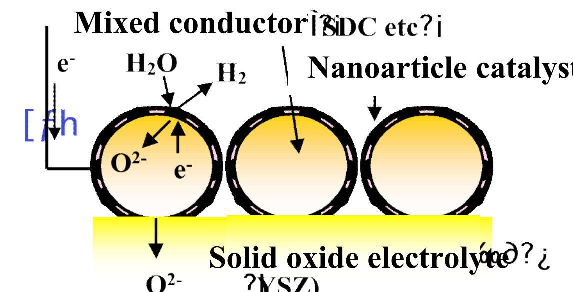
Higher activity

Hi-dispersed Ni-SDC configuration

conventional



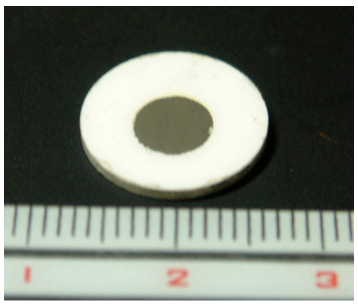
NEW



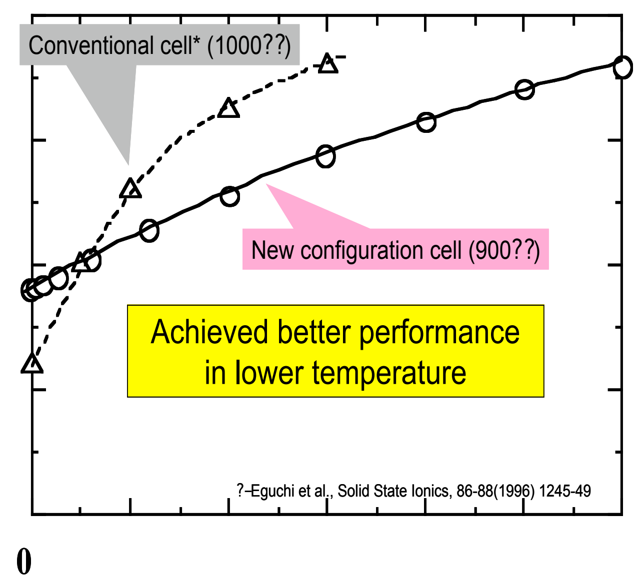
Uchida et al., Electrochemical and solid-state letters, 6(9)A174-A177(2003)

HTE Cell Configuration and Performance

Test Cell (disk-type)



diameter : 13mm
thickness : 0.7mm
Active electrode area
= ca. 0.25cm2



(Cooperation with University of Yamanashi)

* Eguchi et al., Solid State Ionics, 86-88(1996) 1245-49

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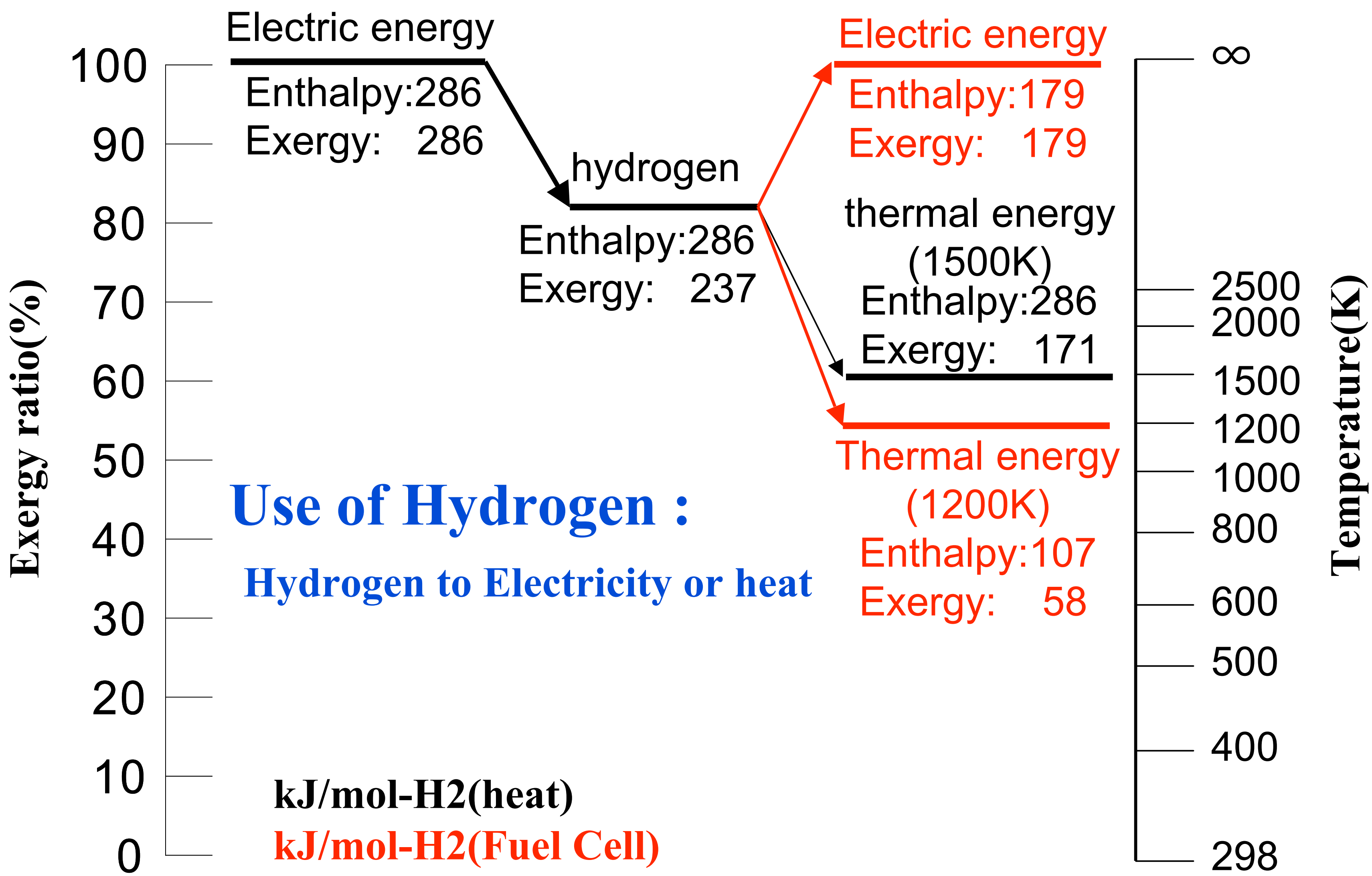

Electric energy
Enthalpy:286
Exergy: 286
hydrogen
Enthalpy:286
Exergy: 237
Electric energy
Enthalpy:179
Exergy: 179
thermal energy (1500K)
Enthalpy:286
Exergy: 171
Thermal energy (1200K)
Enthalpy:107
Exergy: 58
Exergy ratio(%)
100
90
80
70
60
50
40
30
20
10
0
Temperature(K)
∞
2500
2000
1500
1200
1000
800
600
500
400
298
Use of Hydrogen :
Hydrogen to Electricity or heat
kJ/mol-H2(heat)
kJ/mol-H2(Fuel Cell)

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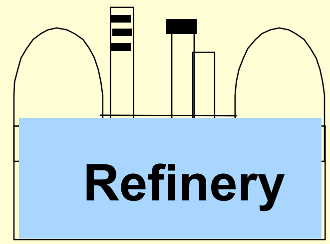
Use of Hydrogen : Hydrogen to Electricity

Transportation

Residential & Commercial

Industrial



Water → **Hydrogen** → **Electricity**

Source = Exhaust
Emission Free

Storable & Convenient
No Black Out

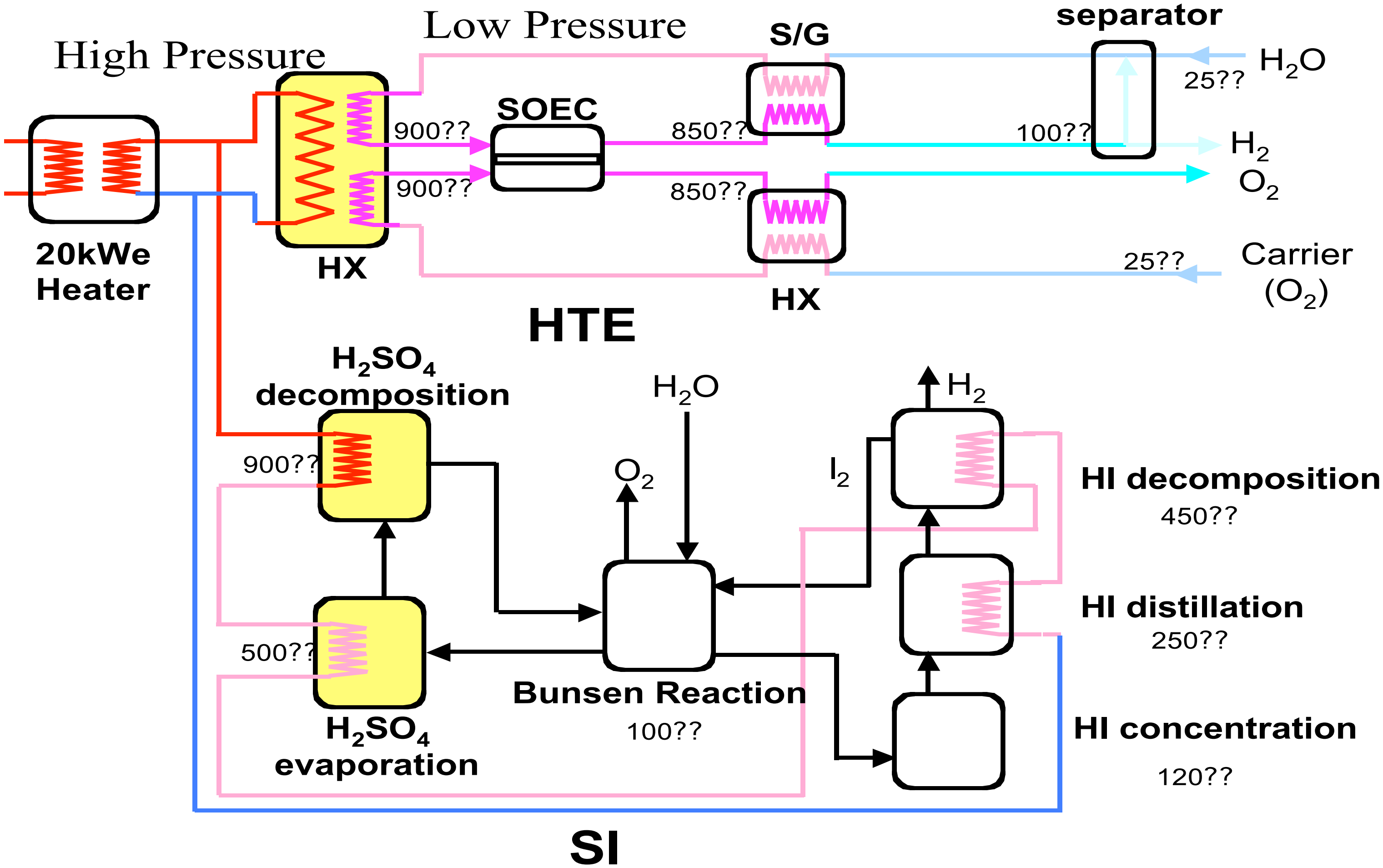
Results from Exergy Ratio Evaluation

Hydrogen shall be produced by lower value energy or combination with small helps of higher value Energy ◆ **Hydrogen production by heat is clever way if possible, if not HTE may be suited**

Hydrogen shall be used for producing higher value energy ◆ **Direct electricity production by hydrogen is better method**

Combination of hydrogen from sufficient high temperature such as gas reactor with fuel cell is preferable method

Toshiba's Engineering Test Loop Plan



Engineering Test will start soon

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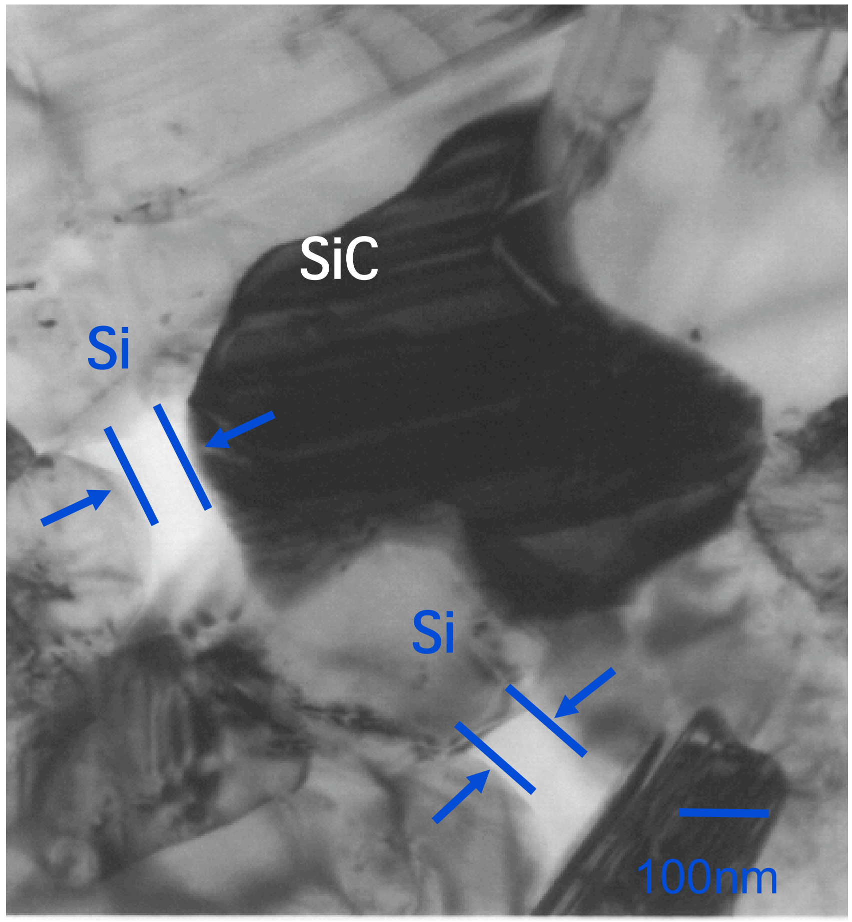
Material Development

	Toshiba developed RS-SiC	Commercial RS-SiC	LSI C/C*)
Density (Mg/m3)	3.1	2.9	2.6 - 2.7
Bending strength ((MPa)	1200	300	50 - 210
Young's modulus (GPa)	400	310	240 - 260
Fracture toughness (MPa·m$^{1/2}$)	3.3	2.0	-
Hardness (Hv)	2000	1600	-
Thermal conductivity (W/mK)	130	120	20 - 135
Specific heat capacity (10^2 J/kg·K)	6.8	5.8	-
Thermal expansion coefficient (10^{-6}/K)	3.9 (RT-1073K) 4.3 (RT-1473K)	3.9 (RT-1073K)	1.8 - 4.1 (293-1273K)
Helium tightness	○	△	△ CVD-SiC coating is required
Cost	0.6	0.6	

*) Per F. Peterson, H. Zhao, University of California, Berkeley, High Temperature Heat Exchanger Project Kickoff Meeting, The University of Nevada at Las Vegas, October 2-3,2003

Microstructure of High Strength RS-SiC



Toshiba controls nanoscale manufacturing process of RS-SiC

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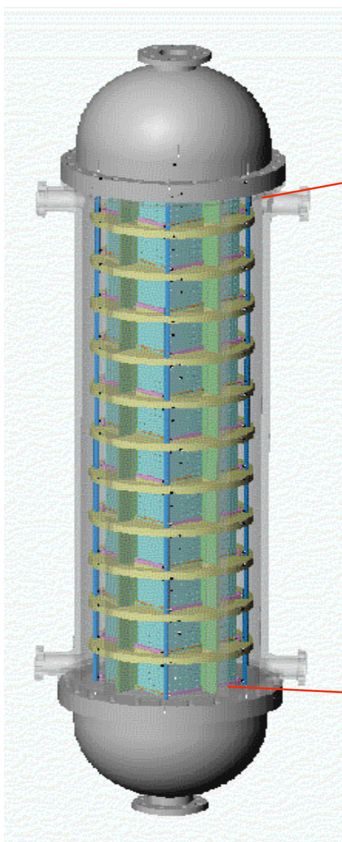
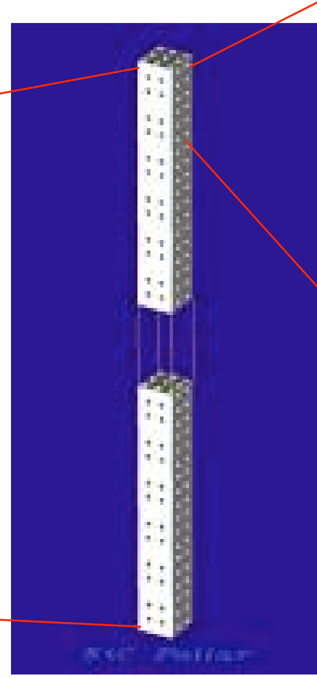
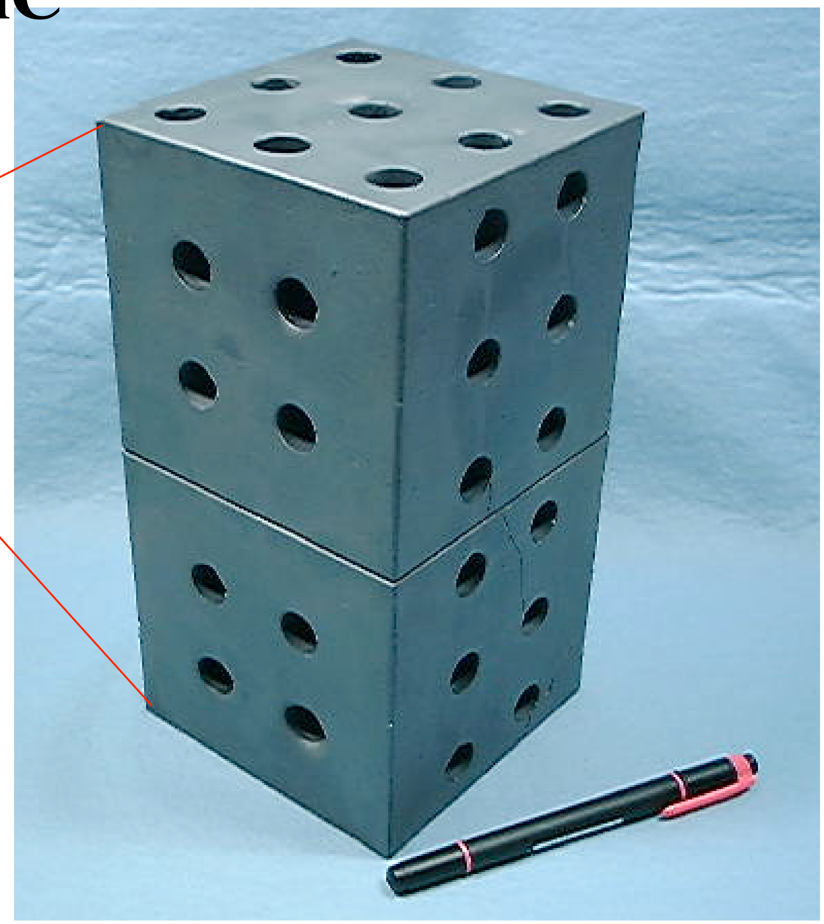
PHX Structure made by RS-SiC

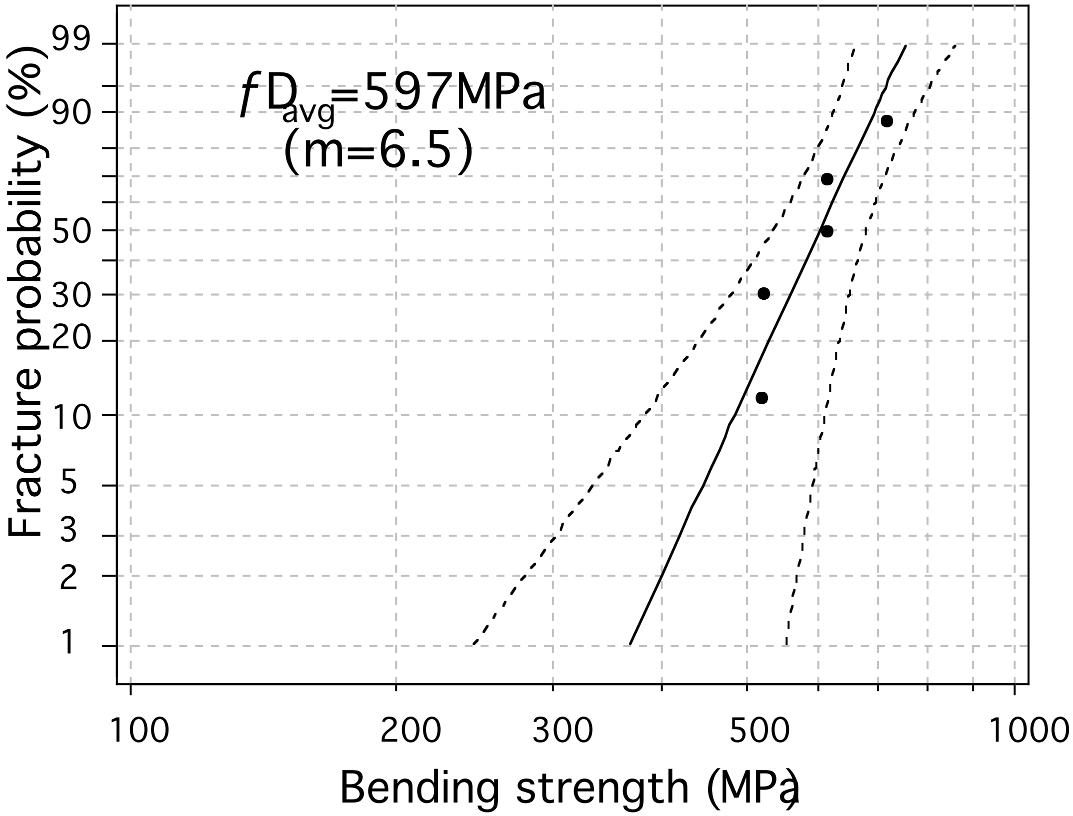






Development of joining procedure for sulfuric acid evaporator

Bending Structure of SiC Joint Parts



Bending structure of joint parts is sufficient for design

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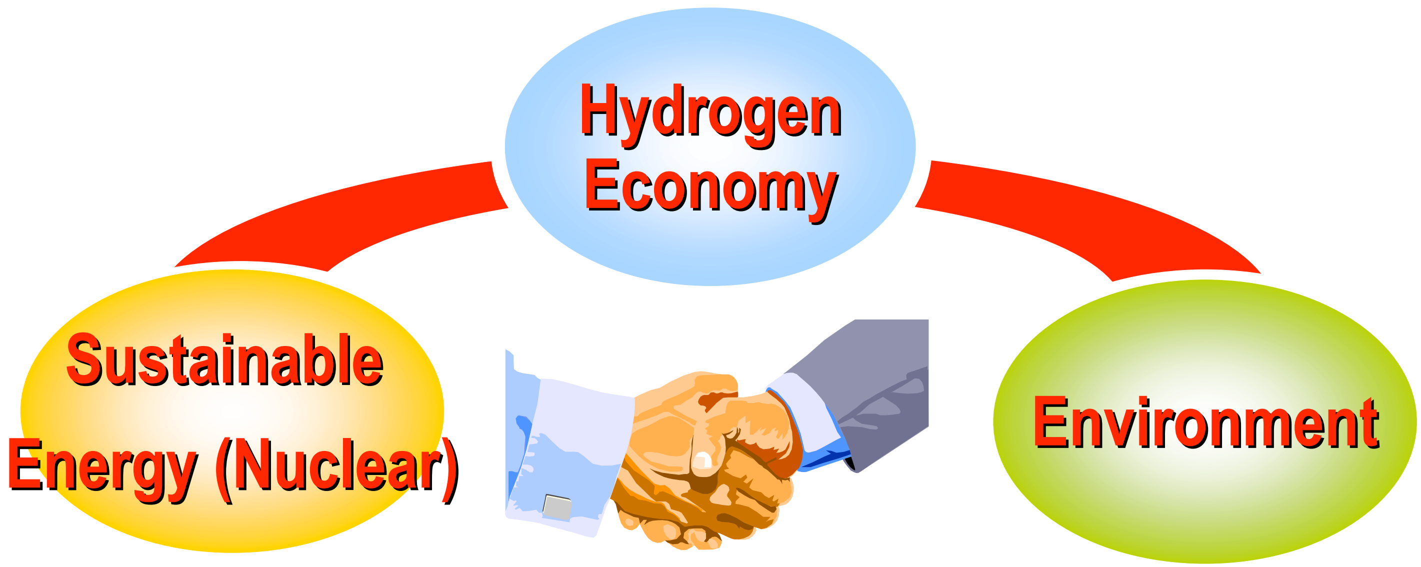
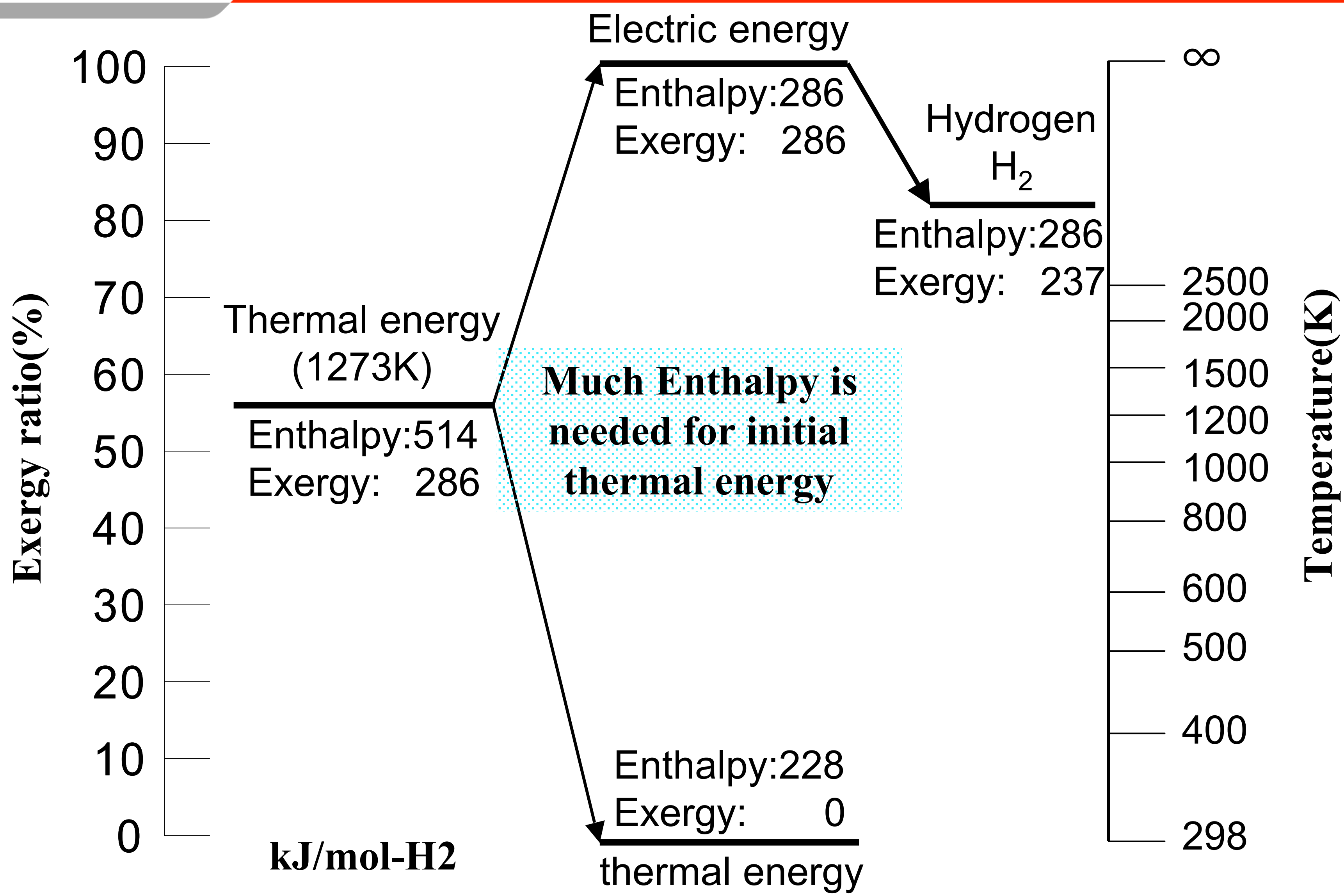
Sustainable development in the 21st Century



APPENDIX

Hydrogen Production by Electricity



Hydrogen Production by Fossil Fuel