Materials Innovations in an Emerging Hydrogen Economy Conference, Feb 24-27 (2008)

Current Status of R&D on Hydrogen Production and Storage in Korea

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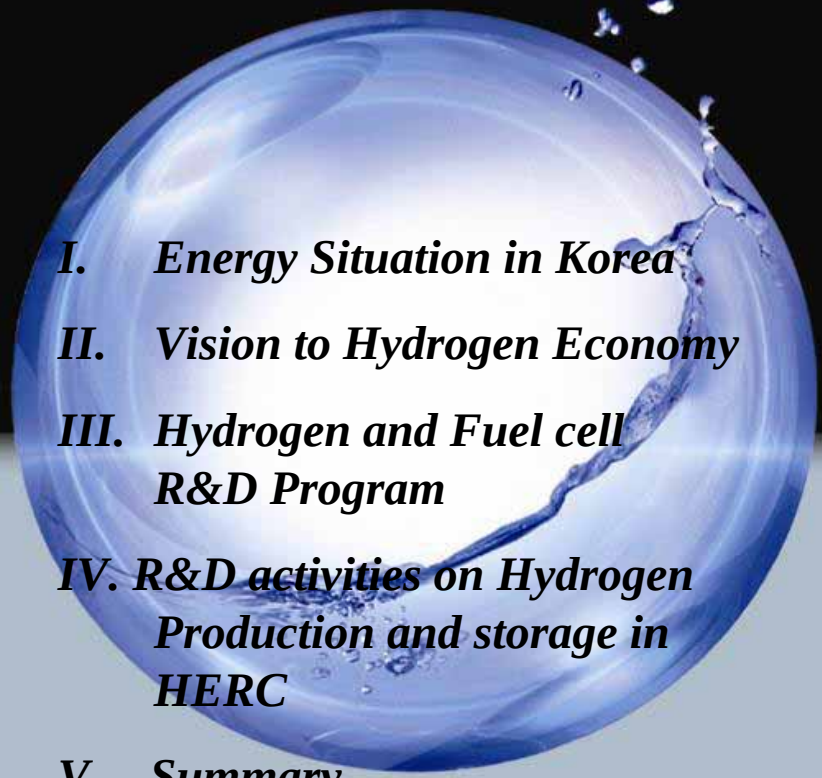
website: http://www.h2.re.kr

Outline



I. Energy Situation in Korea

II. Vision to Hydrogen Economy

III. Hydrogen and Fuel cell R&D Program

IV. R&D activities on Hydrogen Production and storage in HERC

V. Summary

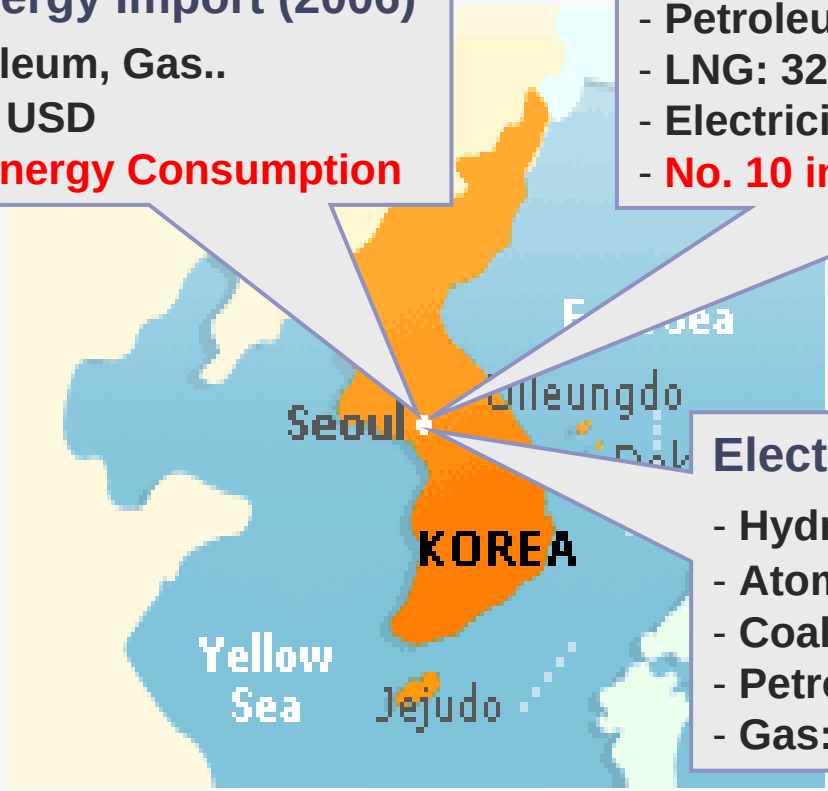
Energy Situation in Korea

Primary Energy Import (2006)

- Coal, Petroleum, Gas..
- 85.6 billion USD
- 96.5 % of Energy Consumption

Energy Consumption (2006)

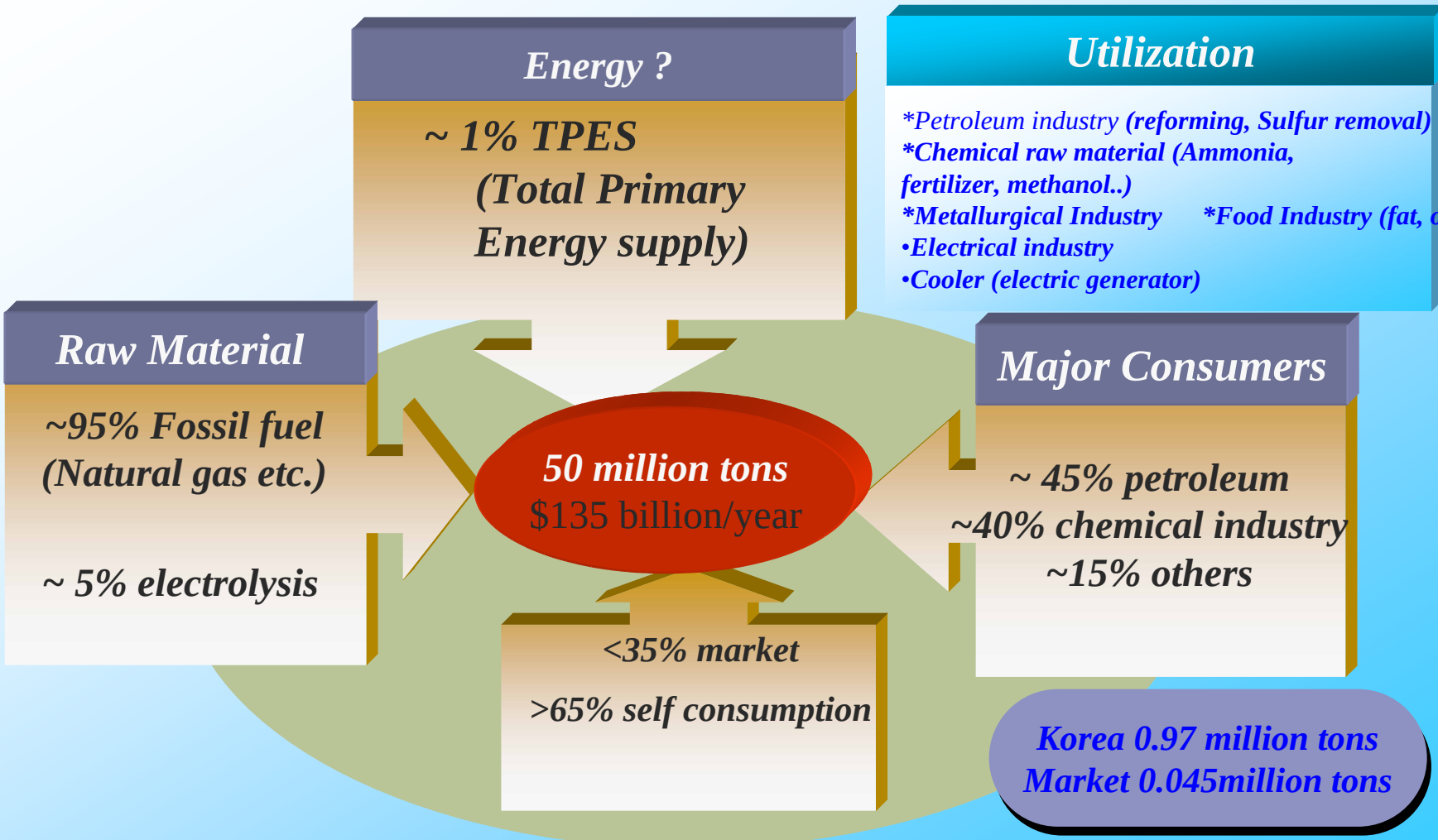
- Coal: 56.7 million TOE
- Petroleum: 101.6 million TOE
- LNG: 32.0 million TOE
- Electricity: 381.1 TWh
- No. 10 in World



Electricity Production (2006)

- Hydro: 1.4 %
- Atomic: 39.3 %
- Coal: 36.8 %
- Petroleum: 4.4 %
- Gas: 18.0 %

Hydrogen Production and Utilization



Hydrogen Economy

"Korea has begun to head for Hydrogen Economy. I am proud of and will support the Hydrogen & Fuel Cell technology during my Presidency. "

(Korea President Lo, riding Fuel Cell Vehicle,'05.3)

Hydrogen Energy : Most Feasible Solution for Energy Problems

↓

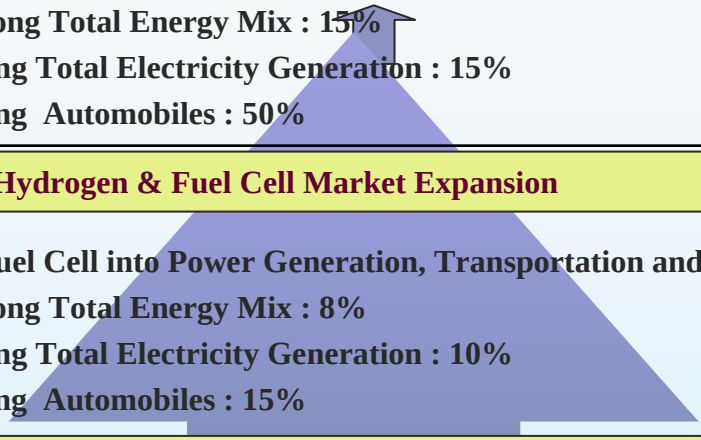
Fuel Cell : Core Technology for Hydrogen Energy Utilization

↓

Selected as One of 10 Economy Growth Engine for Next Generation

→ **2005-N-PS04-P-02 "A National Vision of the Hydrogen Economy and the Action Plan", (MOCIE) (2005.11)**

Scenario by 2040



Phase 4 (~2040) : Hydrogen Economy

Achieve the Economies of Scale by Mass Production of Hydrogen & Fuel Cell

- ✓ Hydrogen Usage among Total Energy Mix : 15%
- ✓ Fuel Cell Usage among Total Electricity Generation : 15%
- ✓ Fuel Cell Usage among Automobiles : 50%

Phase 3 (~2030) : Hydrogen & Fuel Cell Market Expansion

Expand Hydrogen & Fuel Cell into Power Generation, Transportation and Portables.

- ✓ Hydrogen Usage among Total Energy Mix : 8%
- ✓ Fuel Cell Usage among Total Electricity Generation : 10%
- ✓ Fuel Cell Usage among Automobiles : 15%

Phase 2 (~2020) : Hydrogen & Fuel Cell Market Creation

Create New Industries by Commercializing Hydrogen & Fuel Cell.

- ✓ Hydrogen Usage among Total Energy Mix : 2.4%
- ✓ Fuel Cell Usage among Total Electricity Generation : 3%
- ✓ Fuel Cell Usage among Automobiles : 5%

Phase 1 (~2012) : Hydrogen & Fuel Cell Introduction

RD&D and Distribute Hydrogen & Fuel Cell under the support of Government Grant.

- ✓ Hydrogen Fueling Stations: 50 units
- ✓ Fuel Cells for Industrial Power Plants: 300 units
- ✓ Fuel Cells for Commercial Buildings: 2,000 units
- ✓ Fuel Cells for Residential Homes: 10,000 units
- ✓ Fuel Cells for Passenger Car: 3,200 units, Fuel Cells for Bus: 200 units

Summary of Hydrogen & Fuel Cell R&D program

Table 1. Hydrogen & Fuel Cell R&D program in Korea

Program	Sponsor	Period
21st Frontier Program (Hydrogen Energy R&D Center) (www.h2.re.kr)	MOST	2003-2013
National RD&D Organization for hydrogen and fuel cell (www.h2fc.or.kr)	MOCIE	2003-
Nuclear Hydrogen Development and Demonstration Project (NHDD) (www.hydrogen.re.kr)	MOST	2004-2021
Korea IGCC RDD&D Organization (www.igcc.or.kr)	MOCIE	2006-2014

MOCIE: Ministry of Commerce, Industry and Energy
MOST: Ministry of Science and Technology

HERC

(Hydrogen Energy R&D Center)

- **Role**
  - Develop and conduct the National Hydrogen Energy R&D Program
- * 21st Century Frontier Program

R&D Period

- 01 Oct. 2003 ~ 31 March 2013 (9.5 years for 3 phases)

R&D Fund

- Total 111 million US dollars
  (Government : 95 million dollars, Industry : 16 million dollars)

Sponsoring Ministry

Ministry of Science & Technology, Republic of Korea

Source: www.h2.re.kr

R&D Activities in the Phase II (HERC)(2006-2009)

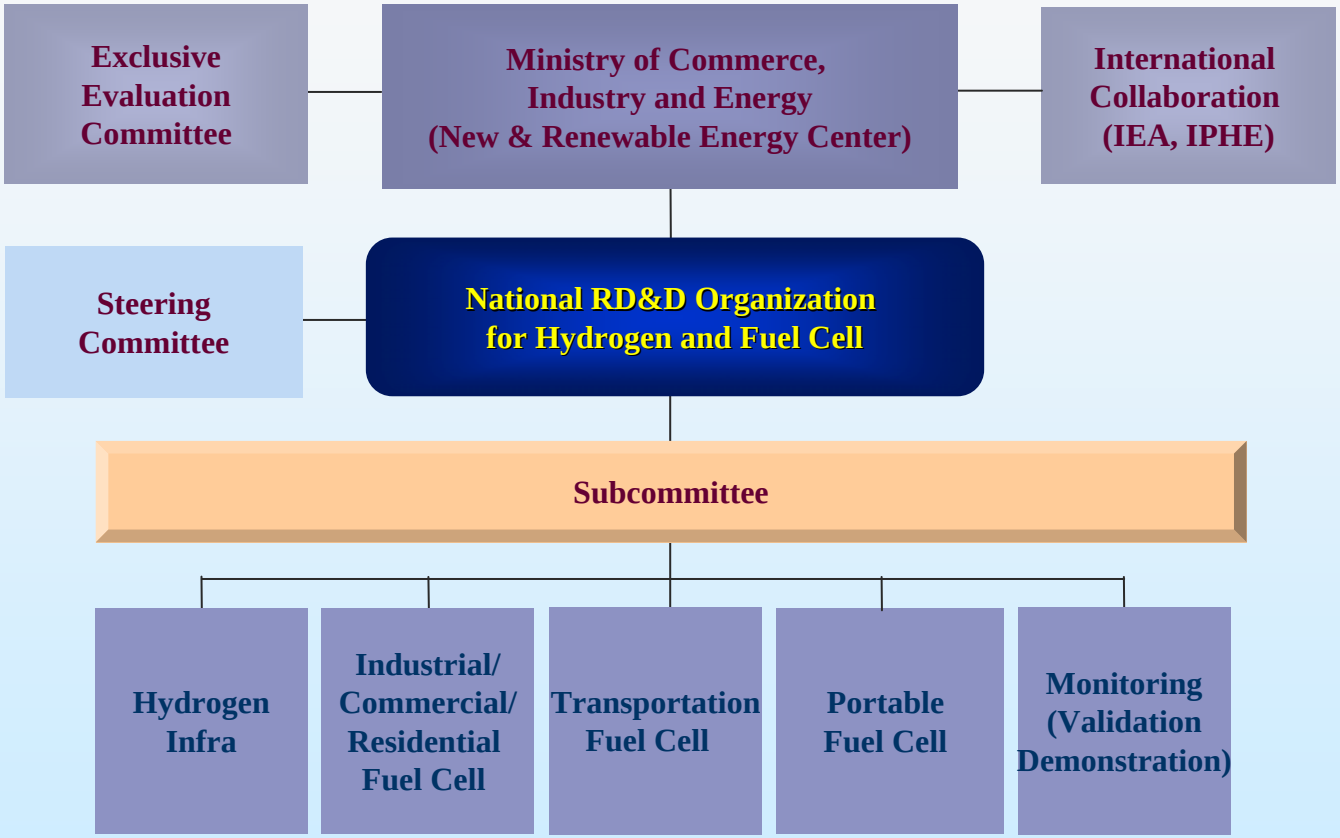
	Action type	
Hydrogen Production		
▸ NG steam reforming for hydrogen station	(AR/DE)	(Mid)
▸ Biological hydrogen production	(BR/AR/DE)	(Long)
▸ Thermo-chemical hydrogen production	(BR/AR/DE)	(Long)
▸ Photocatalytic and photochemical hydrogen production	(BR/AR/DE)	(Long)
▸ Water electrolysis using PEM and THE	(BR/AR/DE)	(Long)
Hydrogen Storage		
▸ Hydrogen storage using metal hydrides	(BR/AR/DE)	(Long)
▸ Hydrogen storage using nano-structured materials	(BR/AR/DE)	(Long)
▸ Hydrogen storage using chemical hydrides	(BR/AR/DE)	(Long)
Hydrogen Utilization		
▸ Linear power/generation system of hydrogen combustion	(AR/DE)	(Long)
▸ Hydrogen sensor	(AR/DE)	(Long)
Supporting Project		
▸ Measurement techniques for hydrogen storage materials		
▸ Policy and technology assessment		

Priority… Sustainable growth of economy

BR: basic research, AR: applied research, DE: demonstration

Source: www.h2.re.kr

National RD&D Organization for Hydrogen and Fuel cell



- Established in 2003 to expedite the commercialization of hydrogen and fuel cell technology.
- Propose the vision for hydrogen economy in Korea.
- Develop a national plan, road maps and action plans to create a new industry.
- Coordinate and manage RD&D programs supported by MOCIE.

Source: www.h2fc.or.kr

Source: www.h2fc.or.kr

IGCC

- IGCC (Integrated Coal Gasification Combined Cycle) is a technology that generates electric power using coal gasification and gasified fuel.
- The influence on the environment is lower than the pulverized coal power plant.
- The weight of fossil fuel for power generation is remarkably high in Korea.
- Small scale pilot plant for coal gasification has been operated from 1994 in Korea, with objectives of key coal selection parameters and verifying technical feasibility by local manufacturing skill.

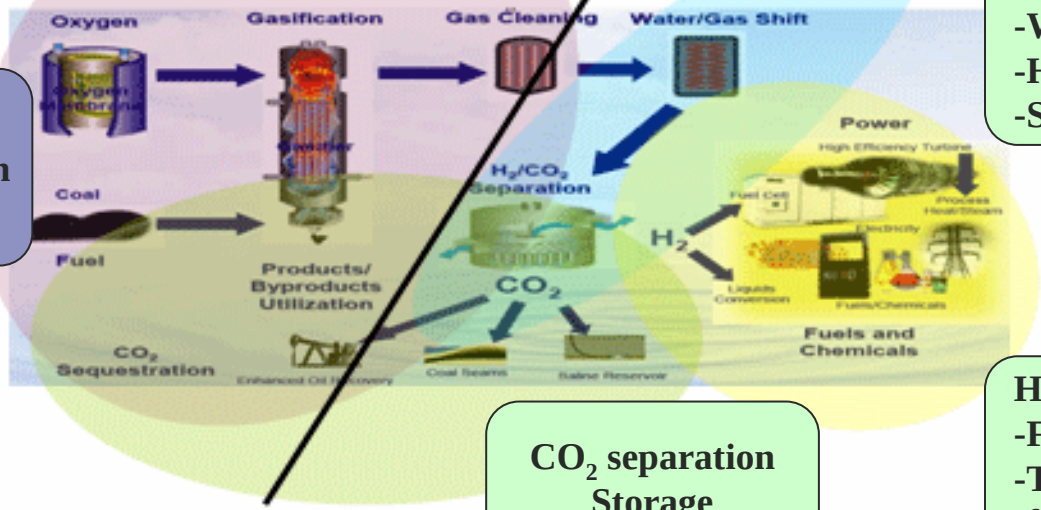
View of 3 Ton/Day-Scale Coal Gasification Pilot Plant

Source: *www.igcc.or.kr*

300MW IGCC demonstration
Plant construction

FutureGen

Coal gasification
Syngas production
and purification



Hydrogen Production
-WGS reaction
-H_2 separation
-Syngas to liquid

CO_2 separation
Storage
And Utilization

H_2 utilization
-Fuel Cell
-Turbine
-fuel

◈Korea government signed an agreement for Korea's participation in the FutureGen International Partnership in June 2006 and the IGCC Project started in December 2006.

Source: www.igcc.or.kr

Korea IGCC RDD&D Organization (MOCIE)

Goal

To design and construct 300MW class IGCC demonstration plant

Technical Target

- **Thermal Efficiency : > 42%[HHV, Net]**
- NOx: <30ppm , SOx: <15ppm
- Self-supporting technology of design : > 90%
- Localization of Equipment : > 90%

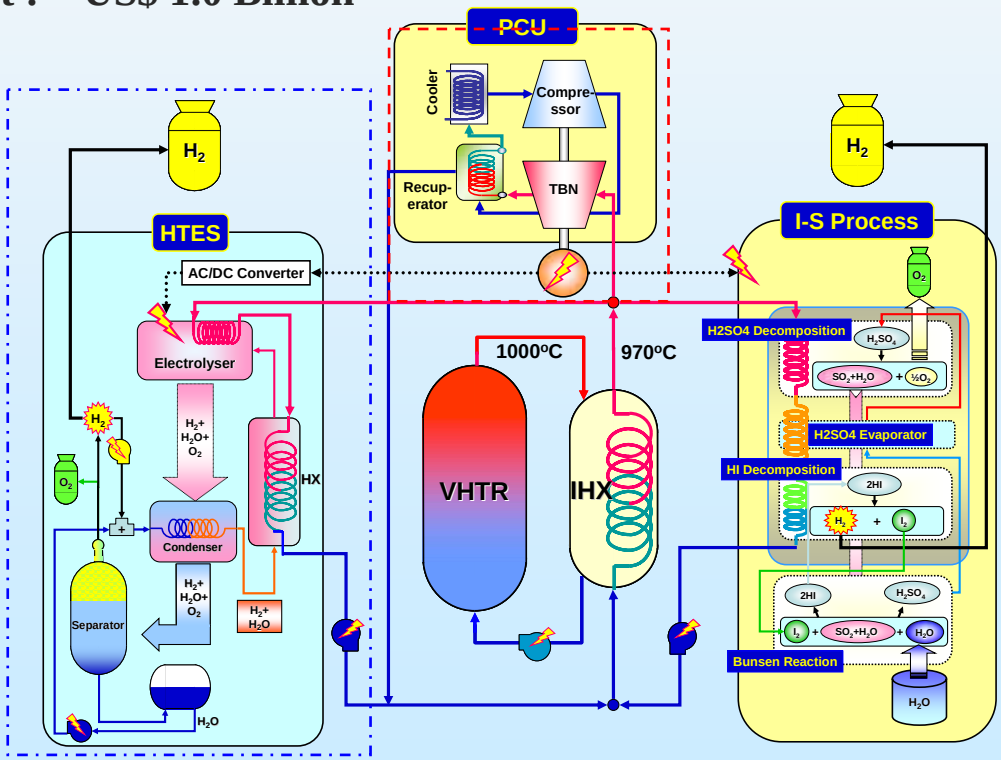
- Launched on 22nd December, 2006
- In the year 2014, 300MW IGCC plant will be constructed and operated
- 599.2 billion won (Government 165.2) .

122.8 billion won (Government 34.7)

Source: *www.igcc.or.kr*

Nuclear Hydrogen Development and Demonstration Project

- **Complete the development and demonstration of the nuclear based hydrogen production technology by the year 2020.**
  - **Period : 2004 – 2020 (17 years)**
  - **Budget : ~ US$ 1.0 Billion**

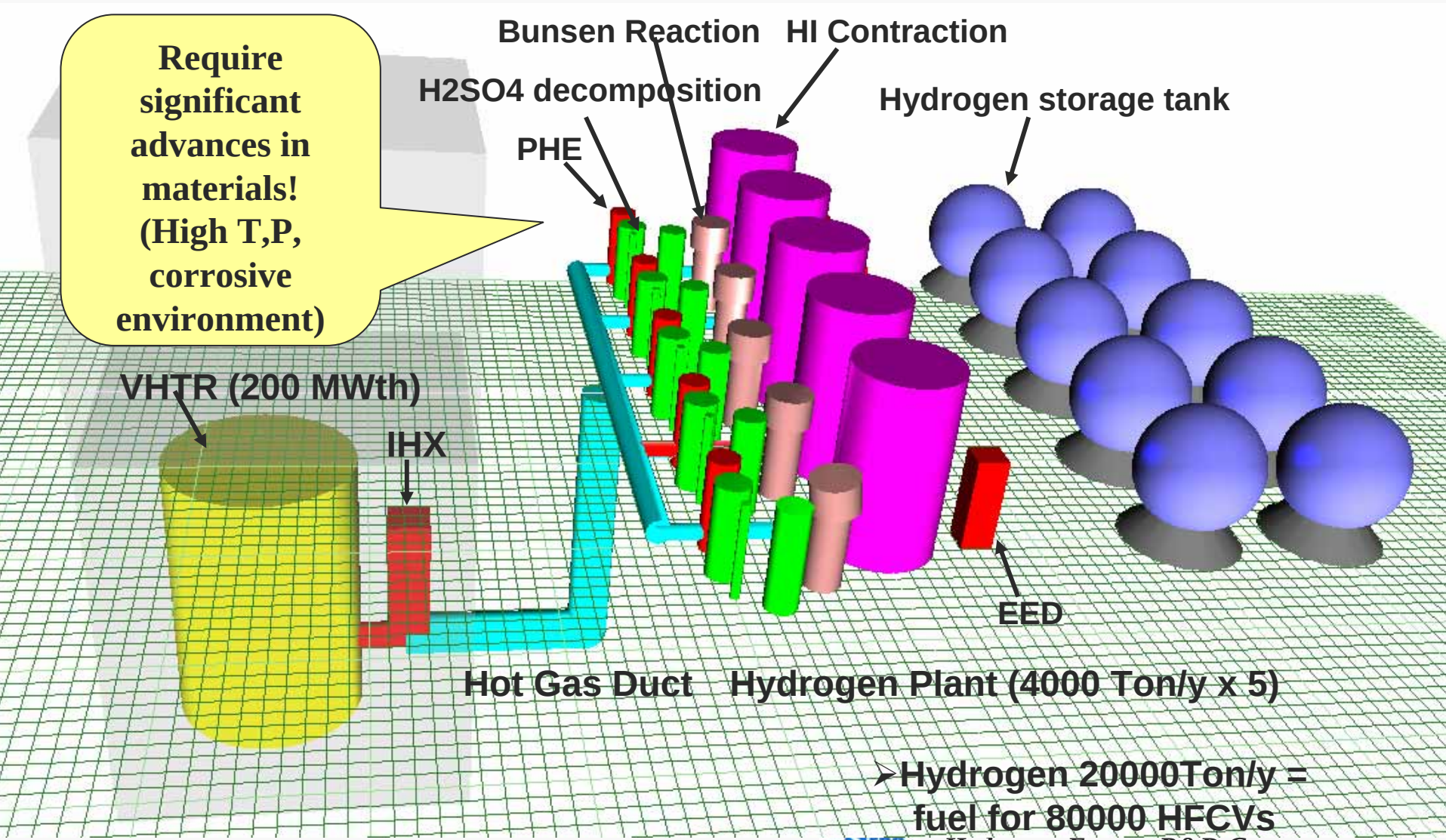


- ✓ 1st phase(2004-2005):12M US$
- ✓ 2nd phase(2006-2009)
- **Reliability of 100l/hr IS cycle**
- **Conceptual design of nuclear reactor**

Source: www.hydrogen.re.kr

Source: www.hydrogen.re.kr

NHDD Plant



➢Hydrogen 20000Ton/y = fuel for 80000 HFCVs

Source: www.hydrogen.re.kr

Project Fund (2007)

Unit :billion KRW

Program	Major Project	2007 Budget
H2FC	Hydrogen Refueling Station/Pressurized Vessel, MCFC/DMFC/PEMFC/SOFC Development of 80kW Class PEMFC Vehicle and 200kWClass PEMFC Bus, Development of Modular Compact FC BOP	40
HERC	R&D on Hydrogen production and storage	10
Nuclear-H2	Nuclear hydrogen	8.5
IGCC*	IGCC plant (300MWth)	34.7
Total (not include IGCC)		**58.5**

- In this R&D plan, hydrogen production is not considered at this time.
- Government side only

Source: www.h2fc.or.kr

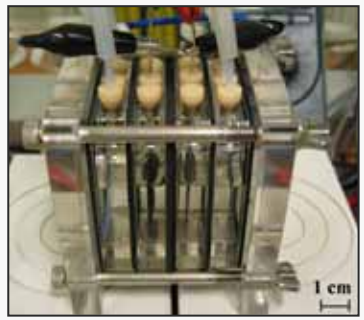
Biological Hydrogen Production

❖ R & D Objectives

-Scale-up and optimization of fermentative H_2 production process and development of bio-mimetic H_2 production system

- Fermentative bioreactor scale : > 500 L
- Fermentative H_2 productivity : 15 Nm^3 H_2/day/m^3
- H_2 productivity by bio-mimetic system : 40 L H_2/kg protein/hr

Organic wastes
650 M m^3/yr
(6% of H_2 consumption)

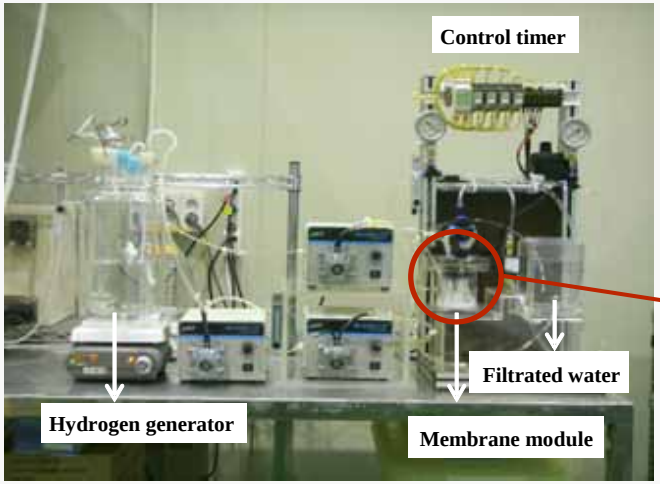


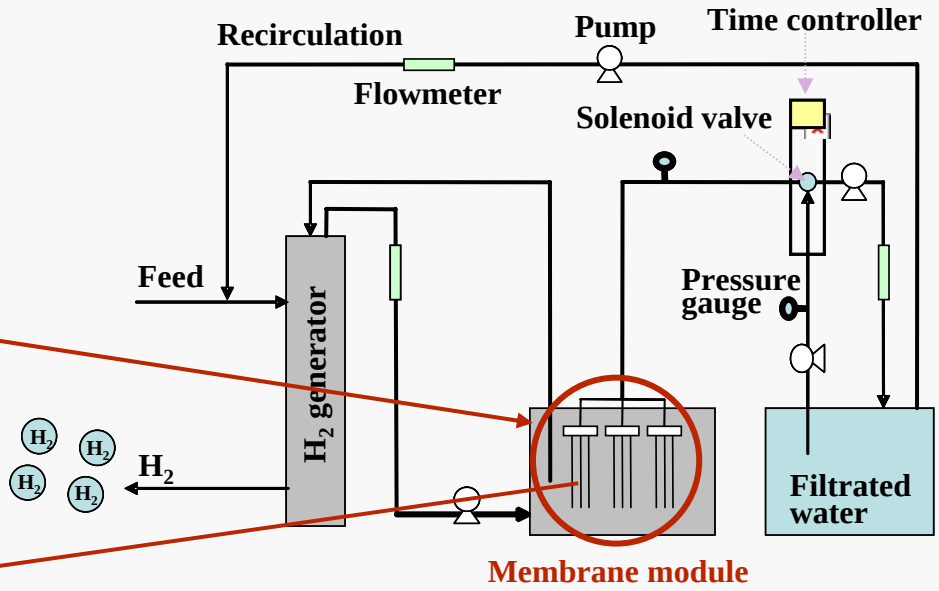
● Recent publications:
- Int.J.Hydrogen Energy, 32, 192-199 (2007)
- Int.J.Hydrogen Energy, 31(11) 1585-1590(2006)
- J. Microbiol.Biotechnol.17,373-377(2007)
- J. Microbiol.Biotechnol.,16, 1210-1215(2006)
- Korea Patent

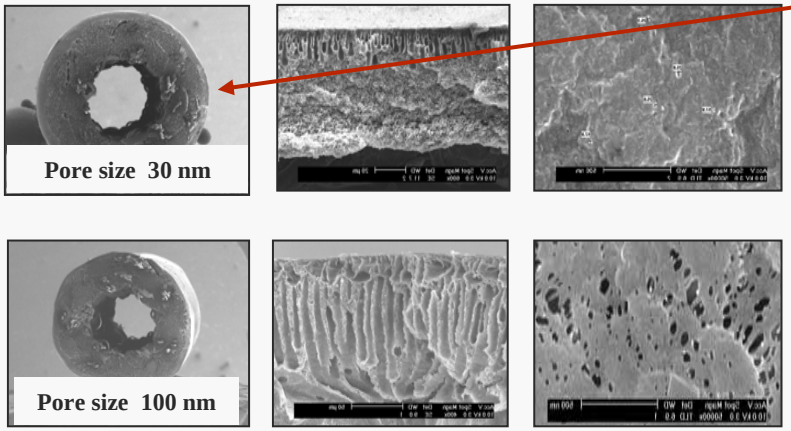
Project Manager: Dr. Kim, Mi-Sun,
bmmskim@kier.re.kr

100 L-scale Membrane bioreactor (MBR) system (Right side)and bio-mimetic H_2 production system(Left side)

Anti-fouling membrane module design and construction







Reactor volume (L)	5
Feed (L/day)	12
20% Filtration of feed (L/day)	2.4
Feed MLSS (mg/l)	10,000
Feed circulation flow rate (L/min)	0.5

Schematic diagram of bio-mimetic H_2 production system

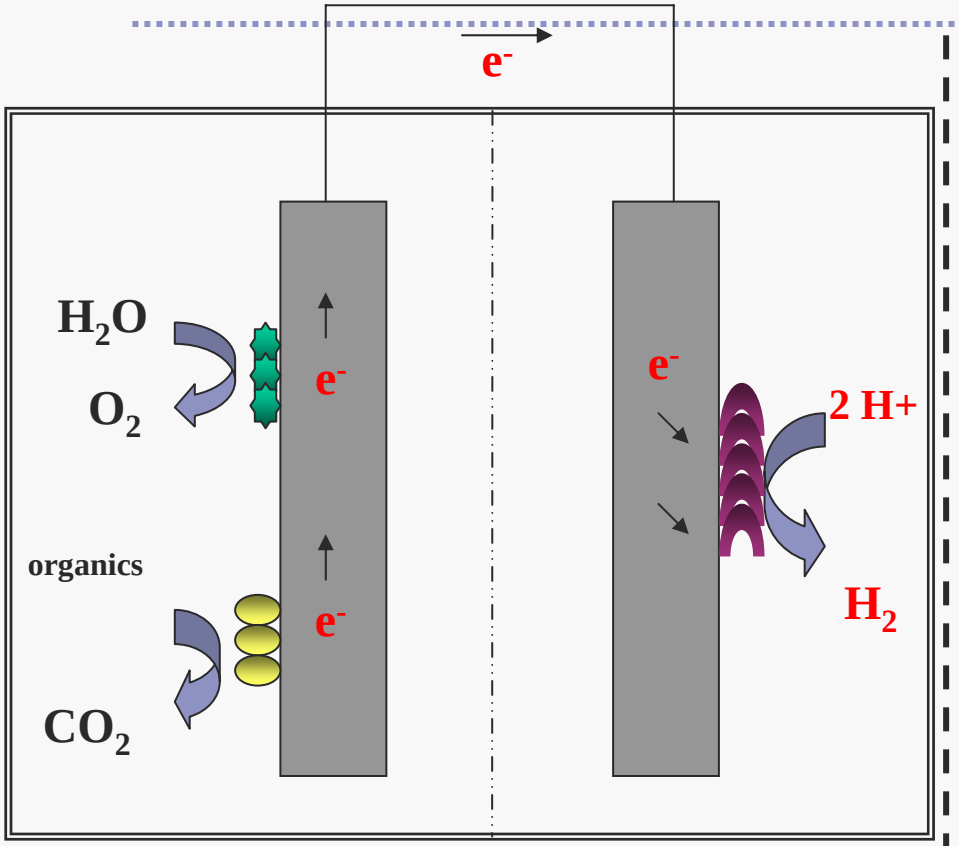


photo-sensitizer (chlorophyil)

microorganism

hydrogenase

R&D Contents:

- **Electron donor/carrier (photosystem, microorganism)**
- **Biopolymer immobilization**
- **System integration**
- **hydrogenase**
  - ✓separation/purification
  - ◆ microorganism modification
    - Genome sequencing
    - Proteomes

Photocatalytic and Photoelectrochemical Hydrogen Production Technology

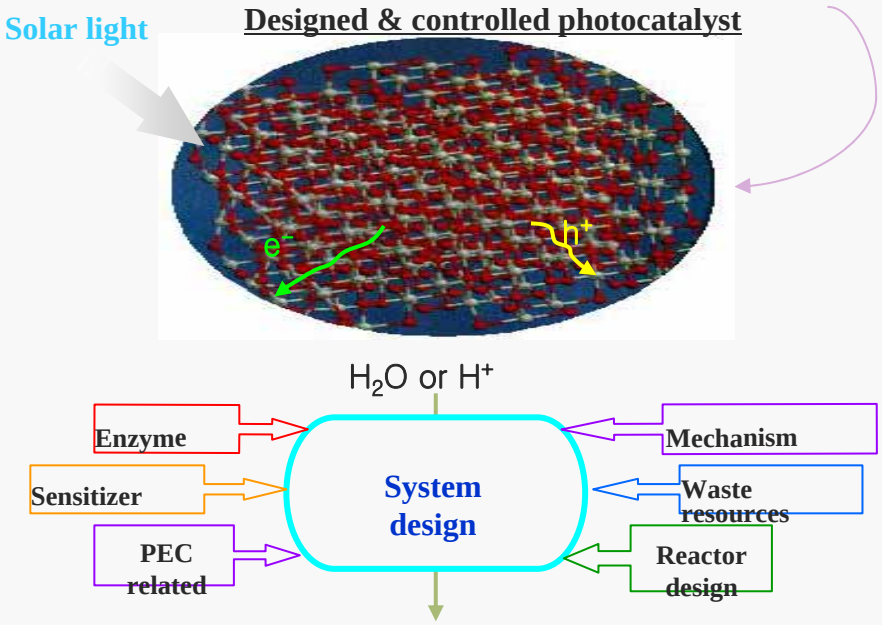
❖ R&D Objectives

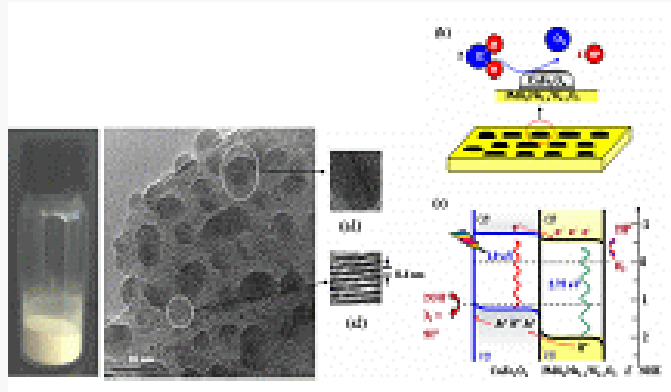
- **Development of the system for 3% solar light conversion efficiency (@AM 1.5) utilizing solar light-sensitizing photocatalyst**
- **System establishment for PEC cell of 7% efficiency**

❖ Content of R&D Activities

- Highly active water splitting photocatalysts- material design
- Tandem-type photoelectrochemical cell modules
- PEC cell of 7% efficiency
- Photo/Biocatalyst
- Q-sized photocatalysts and mesoporous media
- Layered Perovskite and Composite Photocatalysts

KRICT, KIER, KIST, POSTECH, Nanopac





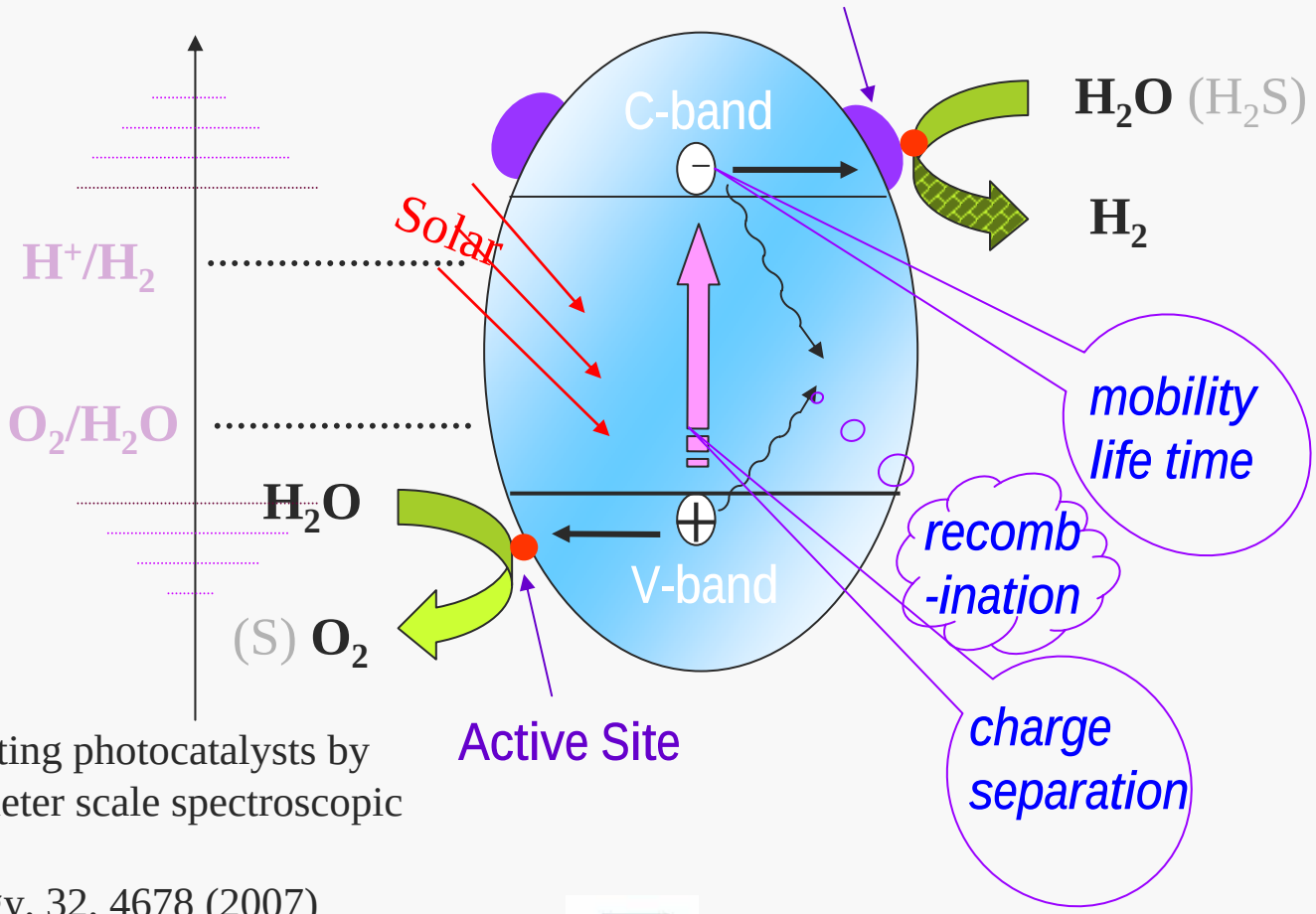
Dr. Moon,Sang-Jin ,moonsj@krict.re.kr

Principle of PC Water Splitting

$2\ H_2O \longrightarrow 2H_2 + O_2$

$\Delta G^\circ = 237.4\ kJ/mol\ (E^\circ = -\Delta G^\circ/nF = -1.23V)$

Overpotentials for photo-splitting of water; 0.6~1.2 eV

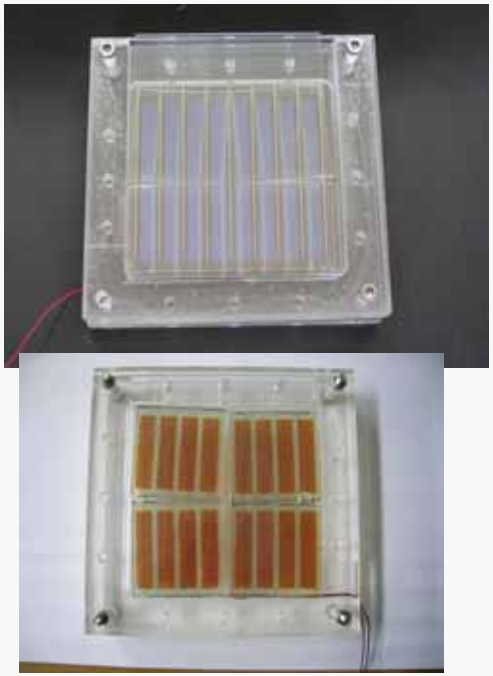


- Highly active water splitting photocatalysts by material design and nanometer scale spectroscopic structural measurement

Int.J.Hydrogen Energy, 32, 4678 (2007)

Journal of material Chemistry, 17, 4297 (2007)

Tandem configuration type water splitting system (10x10cm)

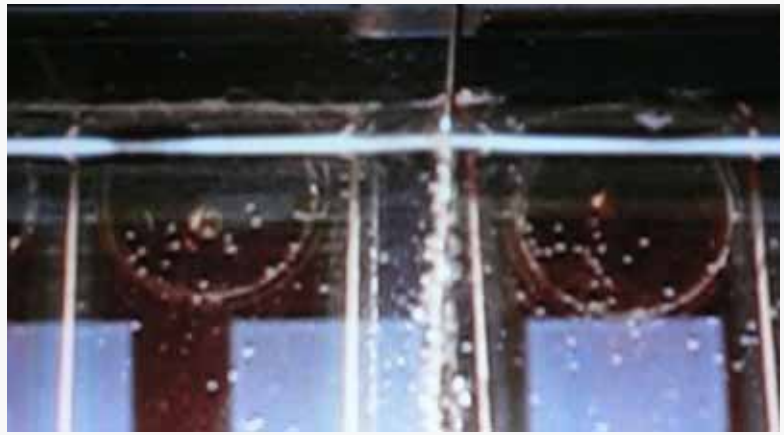


V_{oc} = 2.5V - 3V, I_{sc} = 100~180mA
~2V, 130mA at max. power point

Photograph of prototype tandem PEC cell

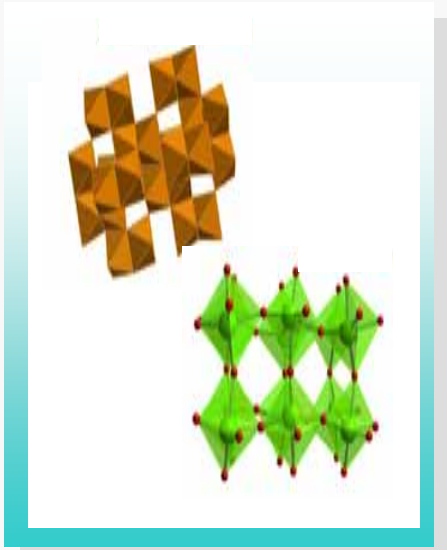
Tandem-type photoelectrochemical cell modules for water splitting

Applied Physics Letters, 90, 1731031-3 (2007)
Solar Energy Materials and solar cells 91(18)1676 (2007)

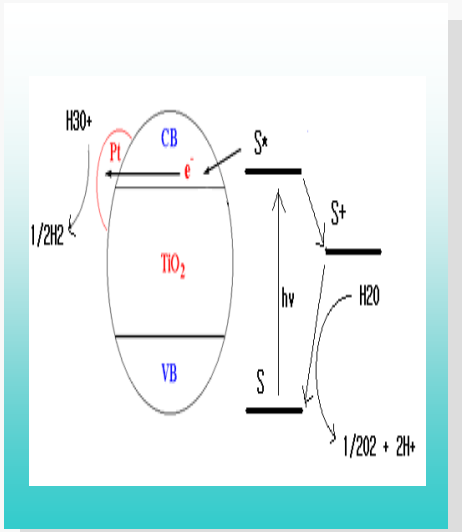


Photograph of water splitting with prototype tandem PEC cell

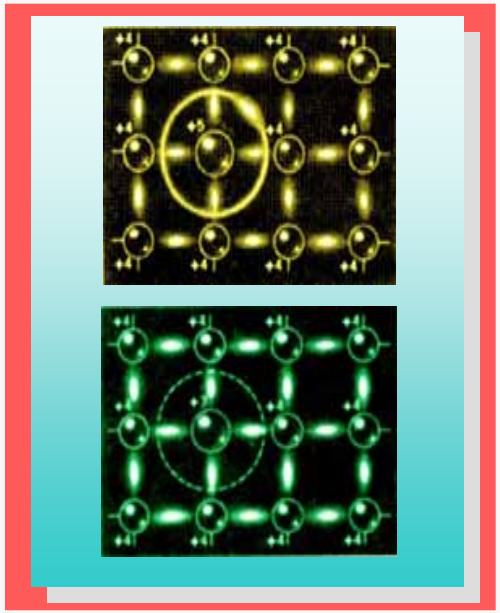
1. WO_3, Fe_2O_3 electrode



2. Visible light photosensitizer

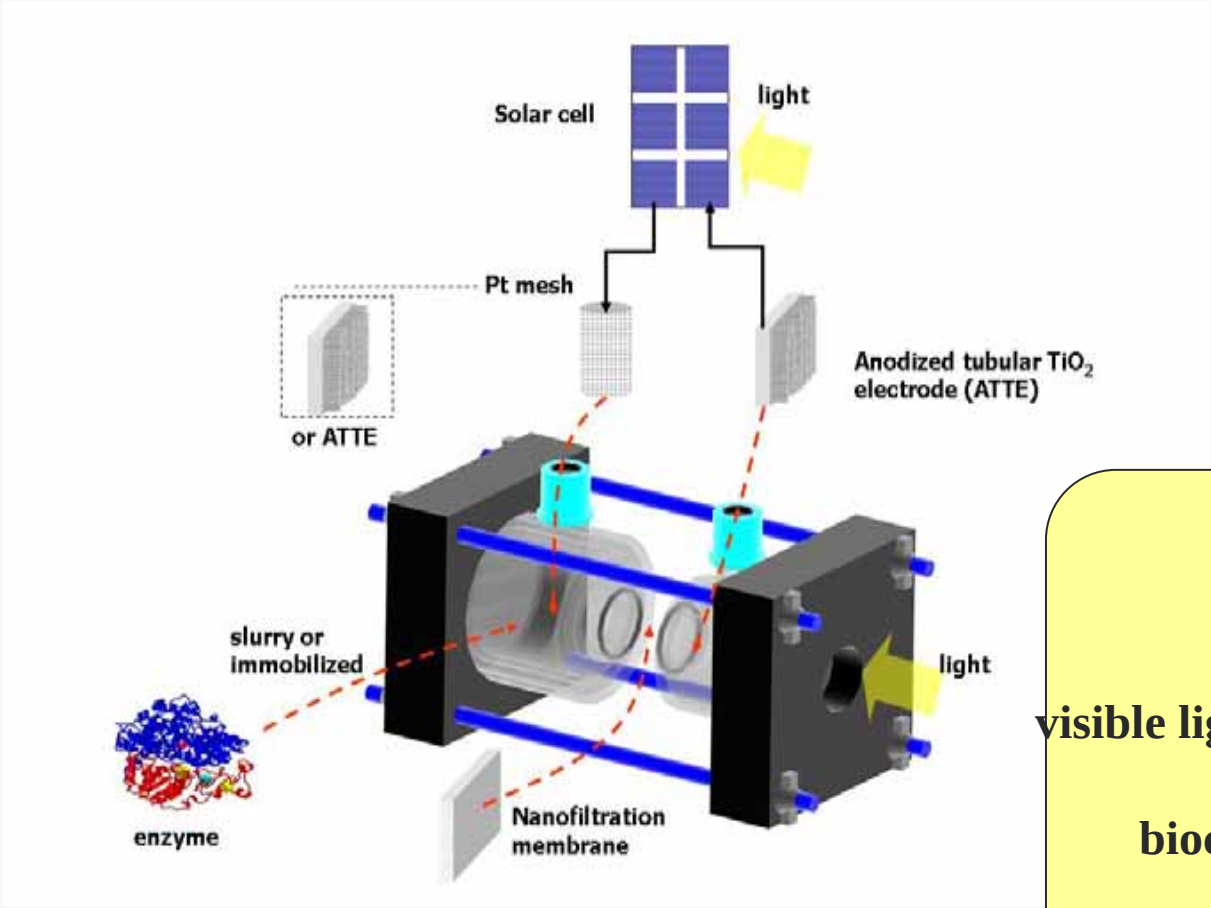


3. p/n type photocatalyst



- Layered Perovskite and Composite Photocatalysts for PEC application
  Angew. Chem.Int.Ed., 44(29) 4585-4589 (2005)

RYN scheme



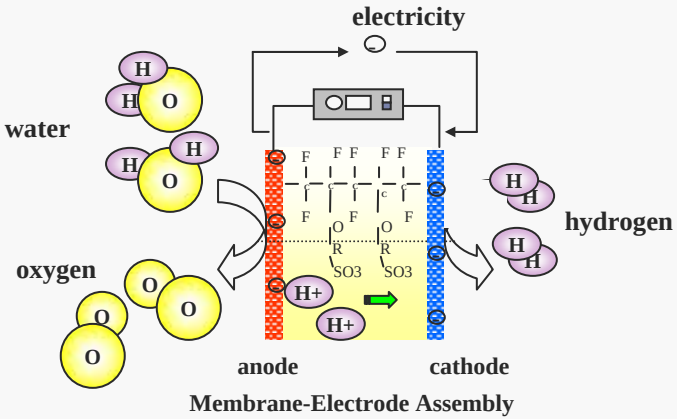
Anode:
visible light sensitized photocatalyst
Cathode:
biocatalyst (hydrogenase)

- Photo/Biocatalytic Hydrogen Production
  J of BWW(baron's Who's Who) Society, 7(5) 1 (2007)

Hydrogen production by electrolysis

❖ Contents of R&D Activities

- PEM electrolysis



- High temperature electrolysis (HTE)

$$\text{Anode} = O^{2-} \rightarrow 1/2O_2 + 2e^-$$

$$\text{Cathode} = H_2O + 2e^- \rightarrow H_2 + O^{2-}$$

❖ R&D Objectives

- **Demonstration of 3Nm^3/h class PEME(Polymer Electrolyte Membrane Electrolysis) system**
- **Development of 50 L/h class HTSE(High Temperature Steam Electrolysis) stack**

● Recent publications:

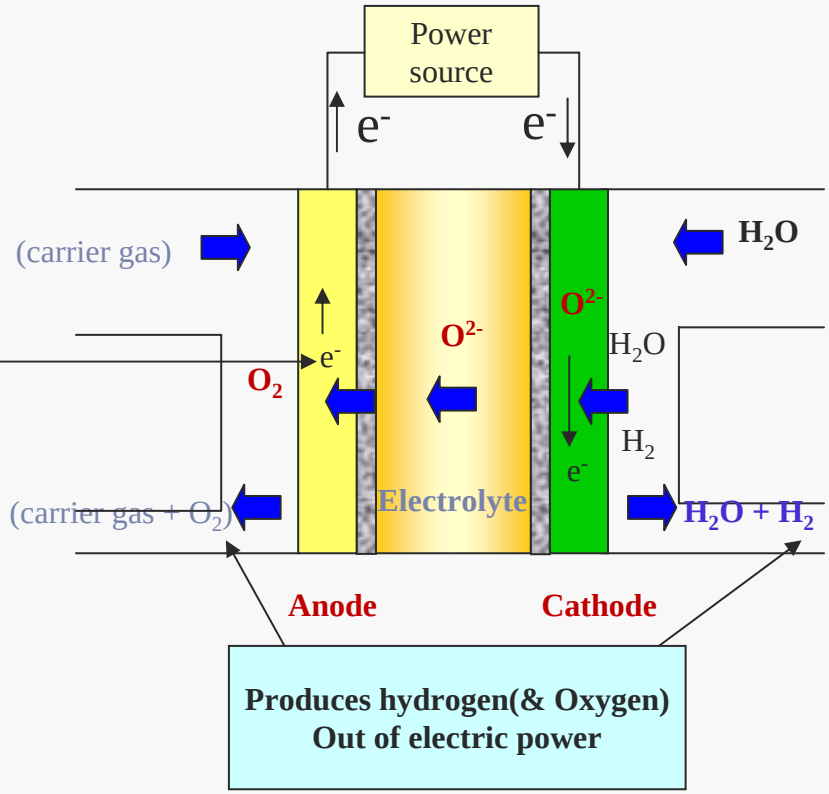
- J. Solid State Electrochemistry 11, 1295-1301 (2007)
- Angewandte Chemie Int. Ed. 46, 8992-8994 (2007)
- J. Alloy and Compound 448, 363-367 (2007)
- J. Alloy and Compound 449, 331-334 (2007)
- Korea Patent 10-0736161/ 10-0756518/ 10-0736163 (2007)

http://www.elchemtech.com/, skwoo@kier.re.kr

High Temperature water electroysis

- Higher activity
- Better gas diffusion
- Higher ionic conductivity
- Material stability (Electrolyte)

Anode



Produces hydrogen(& Oxygen)
Out of electric power

Flat-Tubular Steam Electrolysis Stack

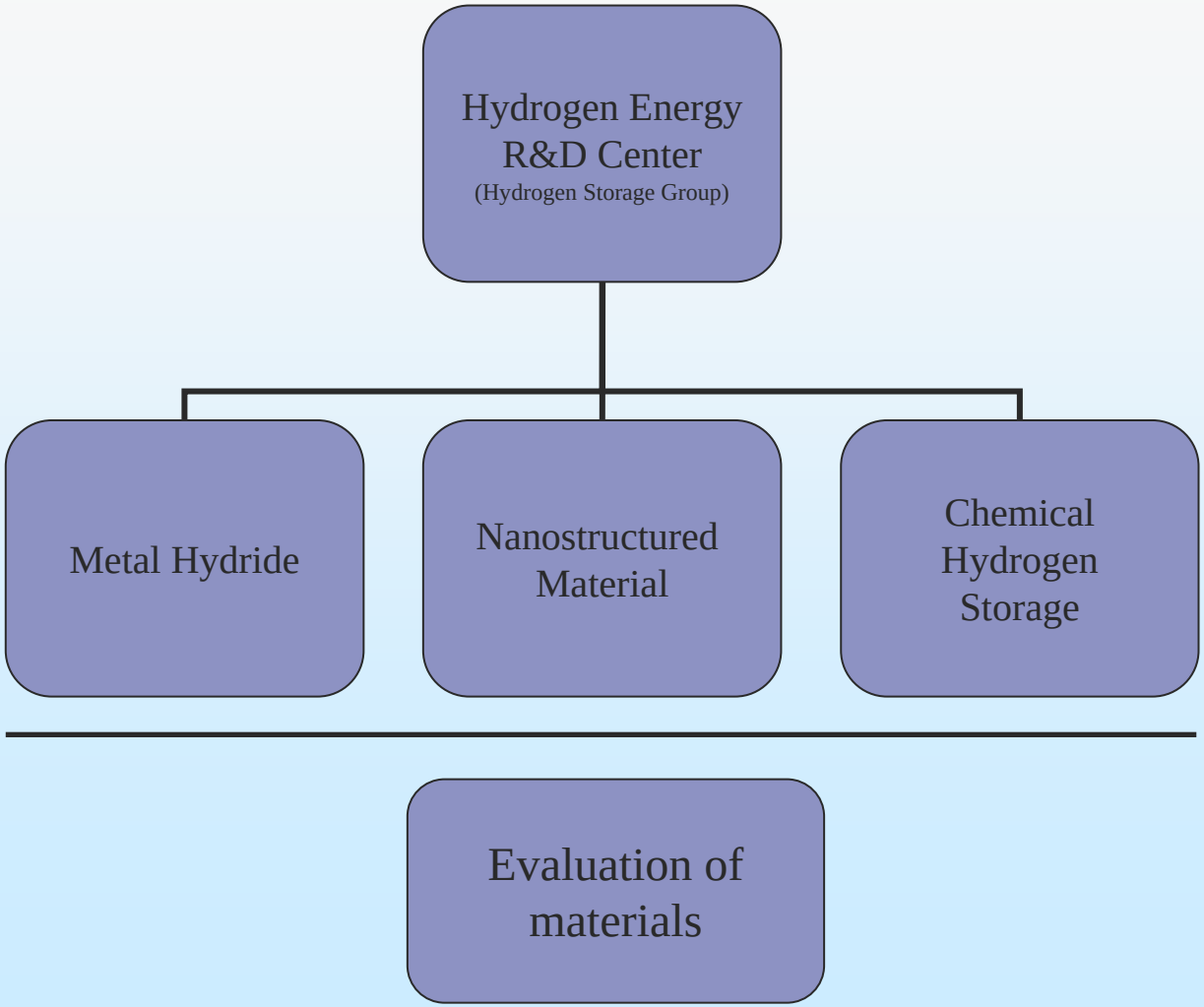
Metallic manifold and current distributor assembly

Brazing/Stacking

Installation

Steam electrolysis stack was fabricated using close-end type of flat-tubular solid oxide electrolysis cells (active electrode area: 120cm^2). The stack was designed so that the gas manifold may be assembled with metallic current distributor.

Strategy: Diverse Portfolio with Materials Focus



- Systematic approach
  - ✓Theory and experiment
  - ✓Independent analysis
  - Universities, companies, Gov-led research institute
- Annual solicitation for increased flexibility
- Close coordination with basic science
- Coordination with other agencies and globally

Metal Hydride Hydrogen Storage for Fuel Cell Vehicle

❖ R&D Objectives

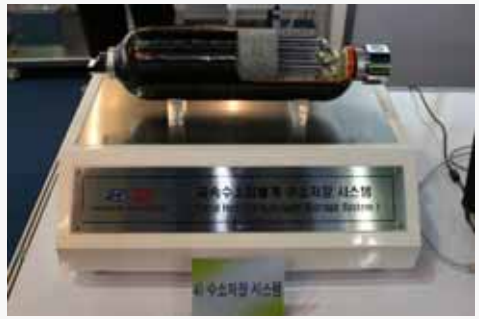
- Develop metal hydride hydrogen storage materials and storage system for fuel cell vehicle (FCV)

❖Content of R&D Activities

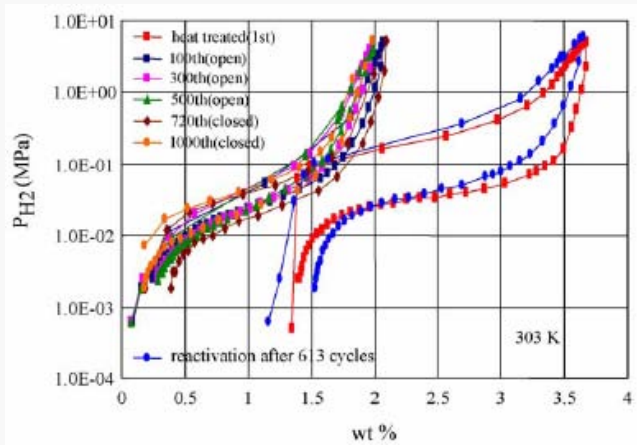
Basic research of metal hydride hydrogen storage systems for a fuel cell vehicle

- Design technology for hydrogen storage vessels
- Hydrogen storage material (T-Cr-V based alloy, Mg-based material, alkali-metal complex hydrides etc.)

Hydrogen storage material



High pressure hydrogen gas tank system



Hydrogen desoprtion/absorption cycle property

B.K.Ahn, bk.ahn@hyundai-motor.com

Hydrogen storage in the porous nanostructured materials

❖ **R&D Objectives**

- Study on the nano-materials for hydrogen storage

❖**Content of R&D Activities**

- High density porous carbon and metal/carbon composites

Surface functionality of nanoporous carbon

- molecular crystals and metal-dispersed materials
- Synthesis of transition metal-dispersed nanotubes
- New material searching/optimization

Optimized materials design using quantum simulations

Searching for new class of hydrogen storage materials: non-covalent bonded molecular crystals

- MOF/organic zeolite

- Preparation of Pt-decorated graphite nanofibers and their hydrogen storage capacity, *J. Colloid Interface Sci.*, **318**, 530 (2008)

-Computational study of hydrogen storage characteristics of covalent-bonded graphenes, J. Am. Chem. Soc. 129, 8999 (2007).

-Effective metal dispersion in pyridinelike nitrogen doped graphenes for hydrogen storage", Appl. Phys. Lett. 92, 01306 (2008).

-Chemical and Engineering News (09/17/2007) : Big Holey MOFs

-Chemistry & Industry (09/24/2007) : MOFs to store gaseous fuels

Core Technology for Chemical Hydrogen Storage

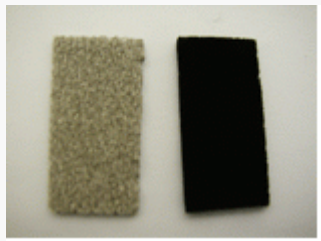
❖ **R&D Objectives**

- Development of a highly efficient hydrogen storage and generation system using NaBH4 and other chemicals

❖ **Content of R&D Activities**

H_2 Storage Technology	H_2 Release System for Mobile Uses
· $NaBH_4$/$NaBO_2$ Recycling Technologies · Reactor Development	· H_2 Release System · Catalyst Development
Samsung Engineering, KIST, KAIST	

Fuelcell notebook operated by a $NaBH_4$ system



Co-B catalyst coated on Ni foam

Porous Co-P catalyst

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Global Collaboration (Hydrogen Production and Storage)

IEA – HIA **TASK 20**
Hydrogen from water photolysis

IEA – HIA **TASK 21**
BioHydrogen

IEA – HIA **TASK 22**
Solid state hydrogen storage

- **Reversible Solid State Hydrogen Storage for Fuel Cell Power supply system**
  (Russian Academy of Sciences)

- **Focal Point Program on Hydrogen Storage (UK)**

For More Information/Collaboration?

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Summary

- Hydrogen and fuel cell were selected as one of 10 economy growth engine for next decade and are strongly supported by the Government.
  - **Hydrogen Energy R&D Center (MOST) (www.h2.re.kr)**
  - **National RD&D Organization for hydrogen and fuel cell (MOCIE) (www.h2fc.or.kr)**
  - **Nuclear Hydrogen Development and Demonstration (MOST) (www.hydrogen.re,kr)**
  - **Korea IGCC RDD&D Organization (MOCIE) (www.igcc.or.kr)**

- There are lots of hurdles to hydrogen production and storage. We still have to to overcome those barriers. (Will Nanotechnology help?)
  - **Most of problems are in Materials!**
  - **New Materials & Concepts are critical**

- There is nothing either good or bad. But thinking make it so.
- Value is always every where!

Materials Innovations in an Emerging Hydrogen Economy Conference, Feb 24-27 (2008)

Thank you for your attention!

http://www.h2.re.kr