

**R&D status and prospects  
on fuel cells in Korea**

**Hydrogen and  
Fuel Cell**

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**Korea Institute of Energy Research**

## Outline

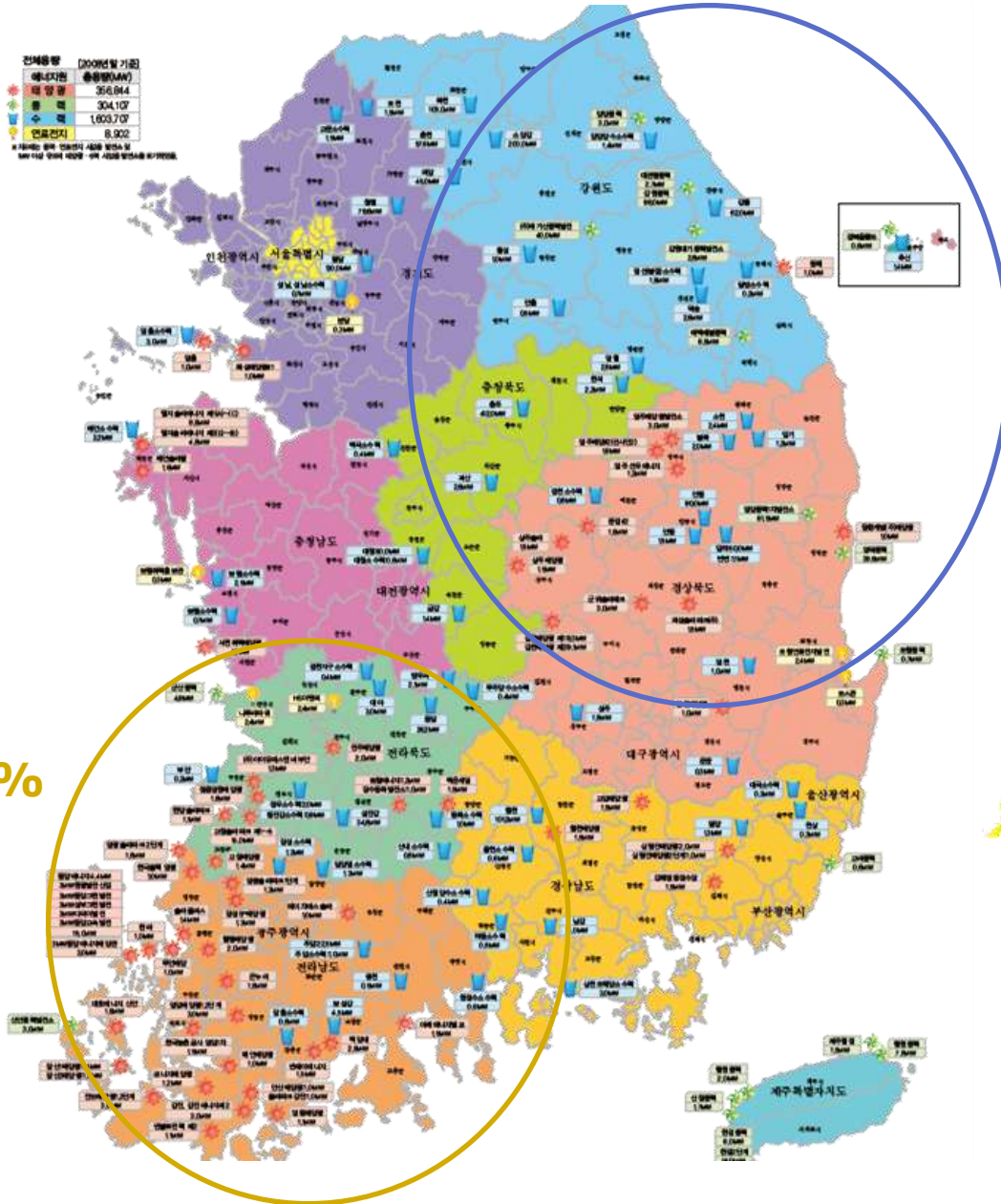
- ✓ **Introduction**
- ✓ **PEMFC : Residential Power Generation**
- ✓ **PEMFC : Fuel Cell Vehicle Applications**
- ✓ **MCFC : Distributed Power Generation and More**
- ✓ **SOFC : Versatile Applications**
- ✓ **Summary**

# New & Renewable Power Generations in Korea

전체용량 [2009년말 기준]

에너지원	총용량(MW)
태양광	347.844
풍력	304.107
수력	1,653.707
연료전지	0.932

\* 태양광, 풍력 에너지의 사용 비중은 20%로, 태양광, 풍력 에너지의 사용 비중은 20%로.



## New & Renewable Energy Map in 2010

~70%

~60%



Solar

347 MW



Wind

345 MW



Fuel Cell

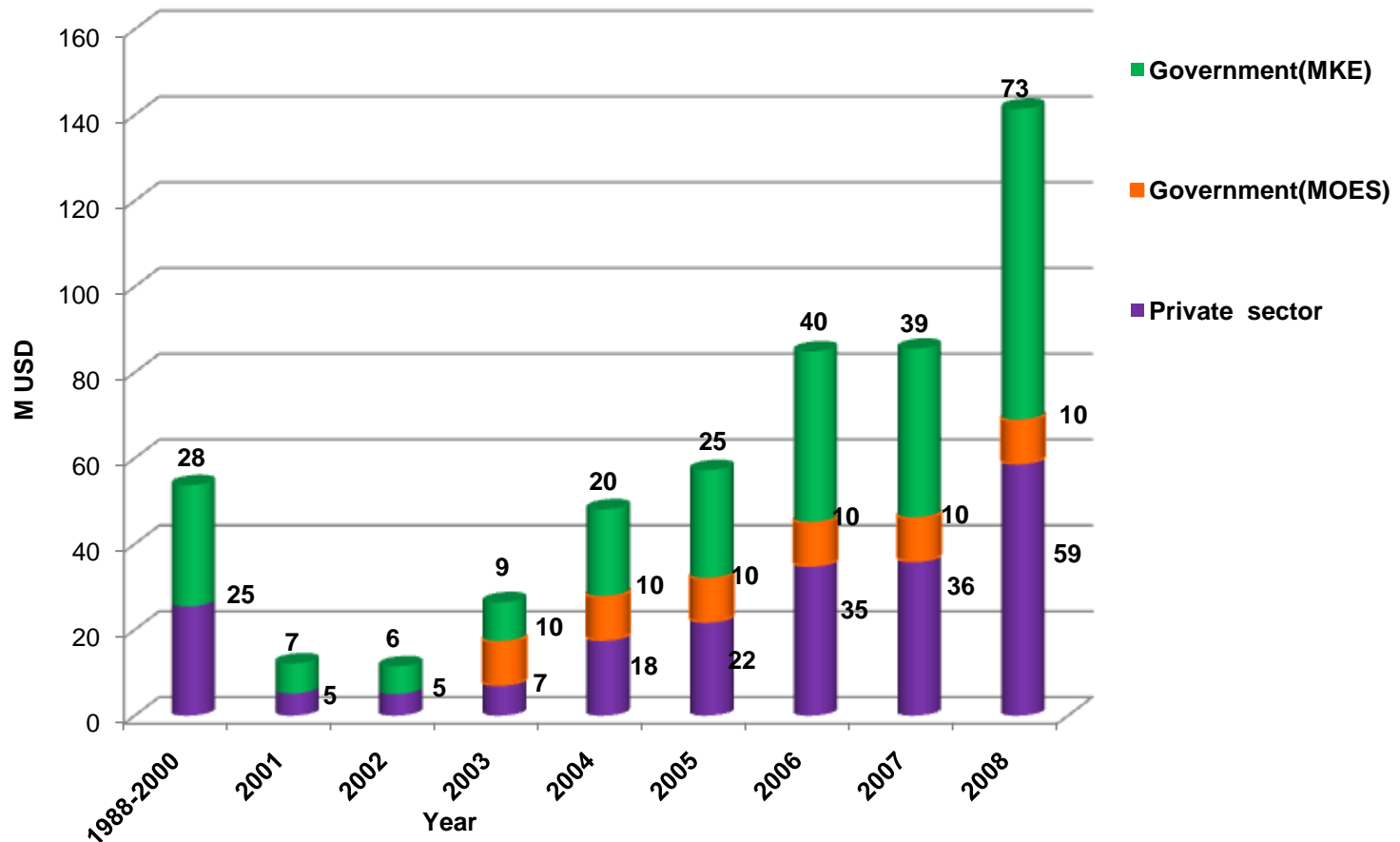
29 MW

### ■ 1988~2003: ~80 Million USD

- Promotion Act for the Development of Alternative Energy (1987)

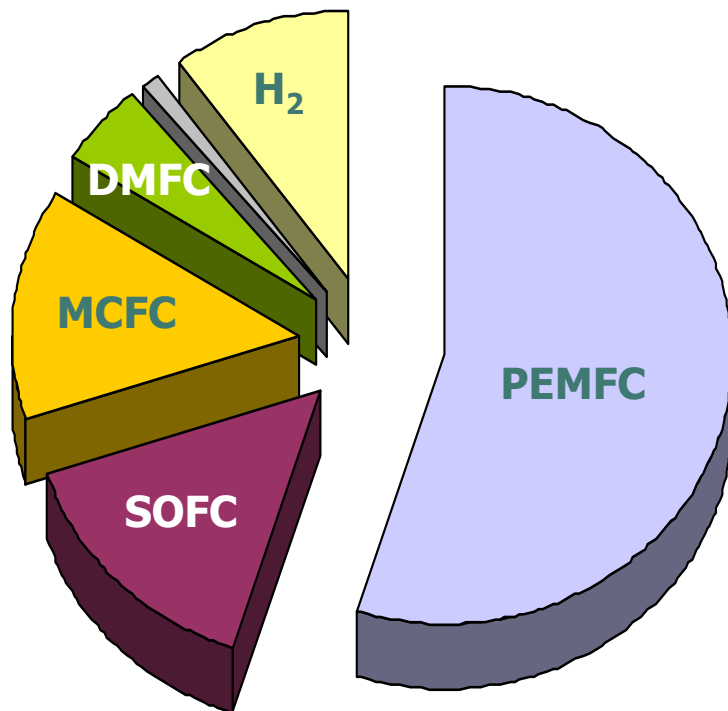
### ■ 2004~2008: ~360 Million USD

- 10-year basic plan for the development and deployment of New and Renewable Energy (2003)

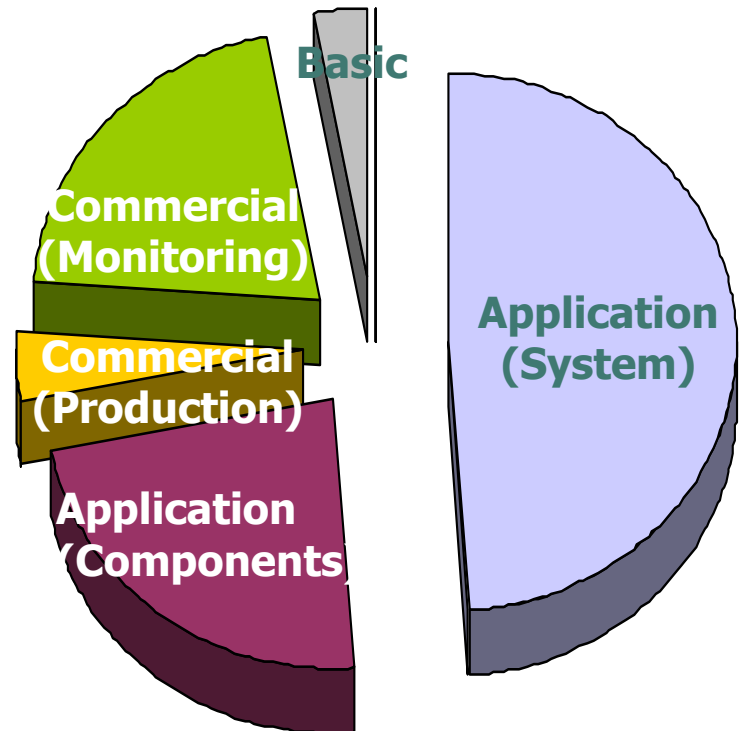


- 37 major projects since 2003

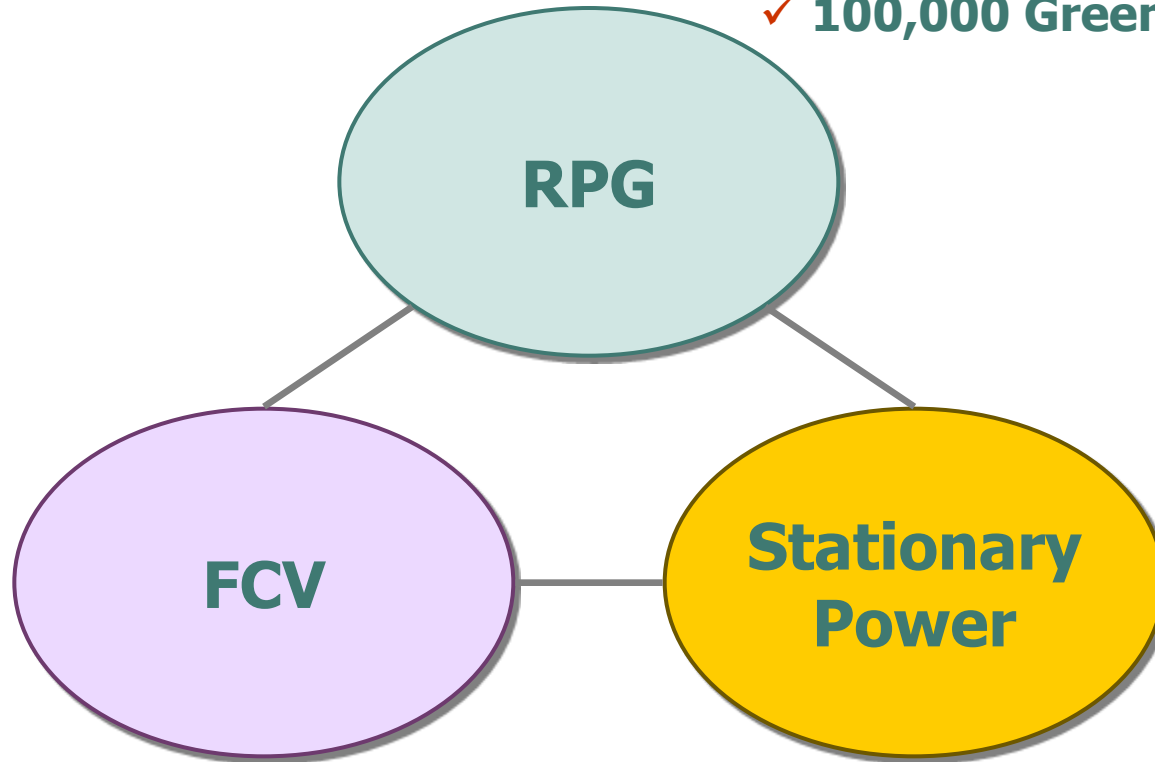
## Technologies



## Characteristics



- ✓ **Monitoring Program**
- ✓ **100,000 Green Homes**



- ✓ **Monitoring Program**
- ✓ **H<sub>2</sub> Stations**
- ✓ **Pre-commercial (Private)**

- ✓ **Feed-in-tariff**
- ✓ **RPS with REC**
- ✓ **Regulation for Public Buildings**



### ❑ Feed-in Tariff

- Korean Government announced year-based feed-in-tariff for fuel cell systems by 2011.
- Total amount of feed-in tariff shall be 50MW.

Fiscal Year	Allowable capacity
~2008	8MW
2009	12MW
2010	14MW
2011	16MW
Total	50MW

### ❑ RPS (Renewable Portfolio Standard)

- RPS shall be in action from 2012 to 2022.
- **49,749 GWh shall be generated by New & Renewable Energy till 2022.**
- Different values for REC (Renewable Energy Certificate) shall be applied to each technology. (e.g.) Fuel Cells using fossil fuels 2.0, Fuel Cells using non-fossil fuels 2.2, Ground Wind 1.0

### ❑ Regulation for Public Buildings

- Shall be applied for public buildings larger than 1,000m<sup>2</sup>
- **10% of power consumption should be supplied by New & Renewable Energy Sources.**
- Expected to be in action after 2012

Seoul City, 『Seoul Low Carbon•Green Growth Master Plan』 (Jul '09)

- Mission : Aggressive Dissemination of Metropolitan Clean Energy

Vision

Global Leader City for Green Growth 'Seoul'

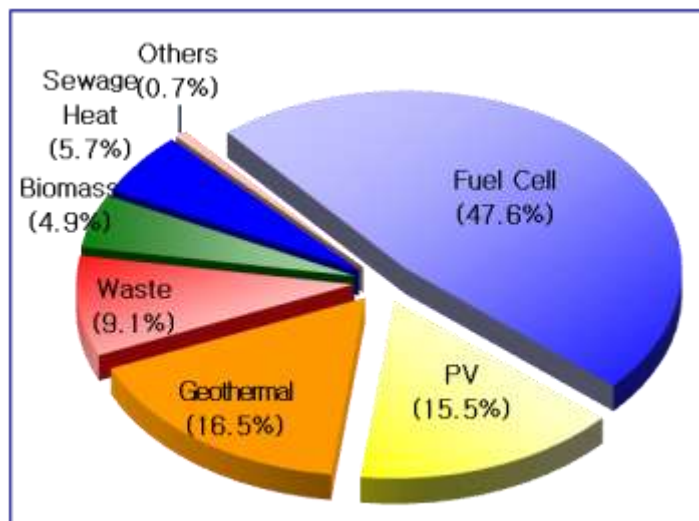
Major Goals

Enviro-Friendly

Green Growth

High Flexibility

[Clean Energy Use by 2030]



[Summary & Methodology]

- **Install FC Power Plant of 600MW for Apartment, Buildings, District Heating**
  - 100MW to Apart/Build, 500MW to CHP
- **Enhance current Regulatory Frameworks**
  - Require FC installation within Newtown
  - Place quota to heavy energy consumers
  - Mandatory Installation of FC in Public Building

※ **Seoul would be the first city to select & focus Fuel Cell Power Plant for Metropolitan Clean & Low Carbon Energy Solution**



# History of Development

PEMFC-RPG



1996~2001

**5kW Prototype**  
By KIER

2004~2006

**3kW System**  
By CETI

2004~2006

**Initial Field Test  
of 1kW System**

Supplied by GS Fuel Cell  
and Fuel Cell Power

Tested by Daegu City  
Gas

2004~2006

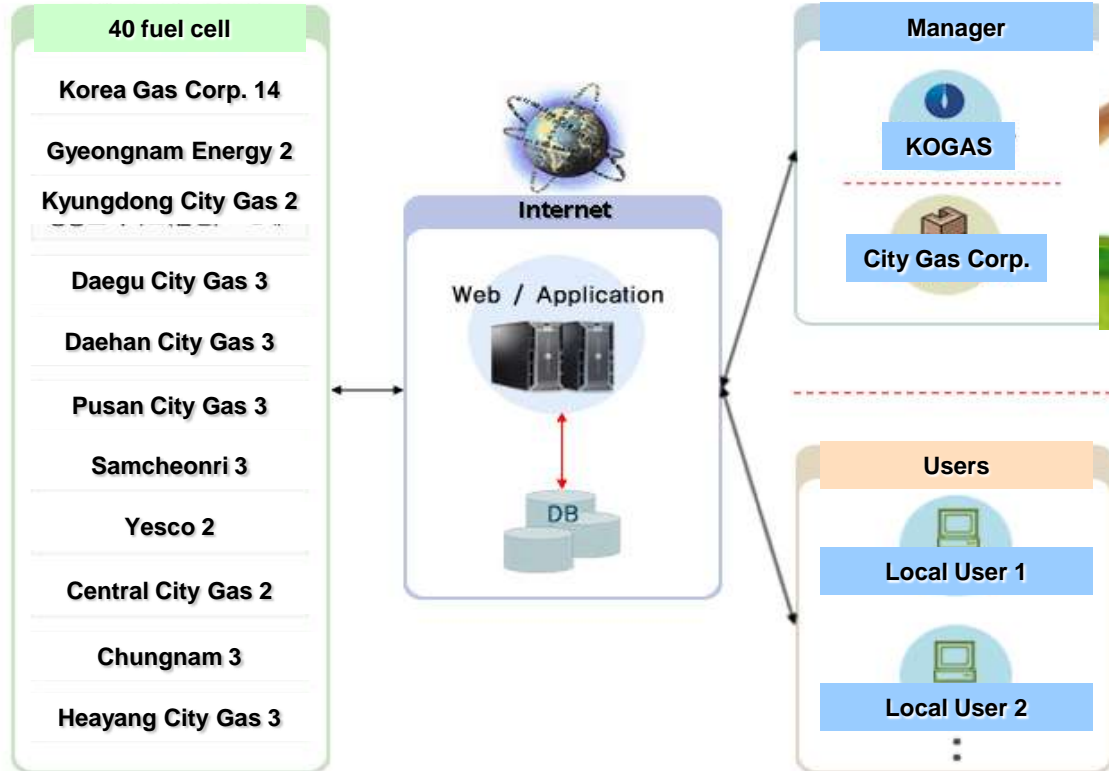
**Field Monitoring Test  
of 1kW System**

Supplied by GS Fuel Cell  
and Fuel Cell Power

Tested by KOGAS,  
Local gas companies,  
and Regional  
governments

- ❑ Provide long-term operation and maintenance data in various sites
- ❑ Improve public acceptance

## Configuration



Year	2006	2007	2008
Number of units	40	70	100
Localization ratio of main components	55%	70%	80%
Price/Unit (mil. KRW)	130	100	80
Site	Gas Co.	Local Governments	

## Selected installation sites



❖ Chungnam City Gas  
(3units, '07.2.3)



❖ Pusan City Gas  
(3units, '07.2.7)



❖ Central City Gas  
(2units, '07.2.15)



❖ Daegu City Gas  
(3units, '07.3.12)



❖ Daehan City Gas  
(3 units, '07.3.23)



❖ Haeyang City Gas  
(3 units, '07.4.6)

# 1kW PEMFC Cogeneration System for RPG

- **Leading Company : GS FuelCell**



Fuel cell	PEMFC
Fuel type	Natural gas
Start-up time	≤ 1 hr
Rated voltage	220VAC 60Hz
Rated electric power	1.0kW
Electrical efficiency	38.5% (LHV)

# 1kW PEMFC Cogeneration System for RPG

## ● Leading Company : Fuel Cell Power



Fuel	City gas (NG)
Output	AC output 1kW
Electrical Efficiency	>38%
Heat Recovery	40% (target), CHP
Grid-Parallel	Grid-parallel, remote control
Start-Up	<1 hr
Fuel Processor	CO<10ppm, H <sub>2</sub> > 75%, efficiency(LHV) 75%
Power Conditioner	Efficiency (>88%)
Stack Temperature	70 - 75°C

# 1kW PEMFC Cogeneration System for RPC

- Leading Company : Hysco



<b>Fuel</b>	<b>City gas (NG)</b>
<b>Output</b>	<b>AC output 1kW</b>
<b>Electrical Efficiency</b>	<b>&gt;39%</b>
<b>Grid-Parallel</b>	<b>Grid-parallel, remote control</b>
<b>Start-Up</b>	<b>&lt;1 hr</b>
<b>Fuel Processor</b>	<b>CO&lt;5ppm, H<sub>2</sub> &gt; 75%, efficiency(LHV) 80%</b>
<b>Power Conditioner</b>	<b>Efficiency (&gt;88%)</b>
<b>Stack Temperature</b>	<b>70 - 75°C</b>



- ✓ **Long-term reliability**
- ✓ **Standardization of BOP's**
- ✓ **High temperature MEA and Stack**
- ✓ **Customer-oriented products and functions**
- ✓ **Volume production and cost down**

# History of Development (HYUNDAI-KIA Motors)

PEMFC-FCV



Small Scale Production

Validation Program  
(2009.12 ~ 2011.11)

• 2012 ~

- Tucson iX FCEV (100kW)

• 2008 ~ 2009

- Borrego FCEV (115 kW)

- FC-BUS Gen II (200kW)

Domestic Monitoring Program  
(2006.08 ~ 2010.07)

• 2007

- Tucson, Sportage FCEV-II (100 kW)

- FC-BUS II (200 kW)

US DOE Fleet Program  
(2004.09 ~ 2009.12)

• 2006

- Tucson, Sportage FCEV (80 kW In House Stack)

- FC-BUS (160 kW In House Stack)

Member of CaFCP  
(2000.11 ~ Present)

• 2004 ~ 2005

- Tucson FCEV (80 kW)

- Sportage FCEV (80 kW)



• 2000 ~ 2002

- Santa Fe FCEV (75 kW)

- Sportage (10kW)



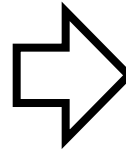
## 2. Fuel Cell R&D Progress in Hyundai-Kia

### Available FCV's

#### 80 kW Fuel Cell Vehicle



Fuel Cell Power	80 kW
Aux. Power	20kW – LiPB
Motor System	80 kW
H <sub>2</sub> Tank	3.6 kg H <sub>2</sub> @ 350 bar
Fuel Efficiency (FTP mode)	20.7 km/l
Driving Range	384 km
Acceleration (0 → 100kph)	16.2 sec
Max. Speed	141 KPH



#### 100 kW Fuel Cell Vehicle

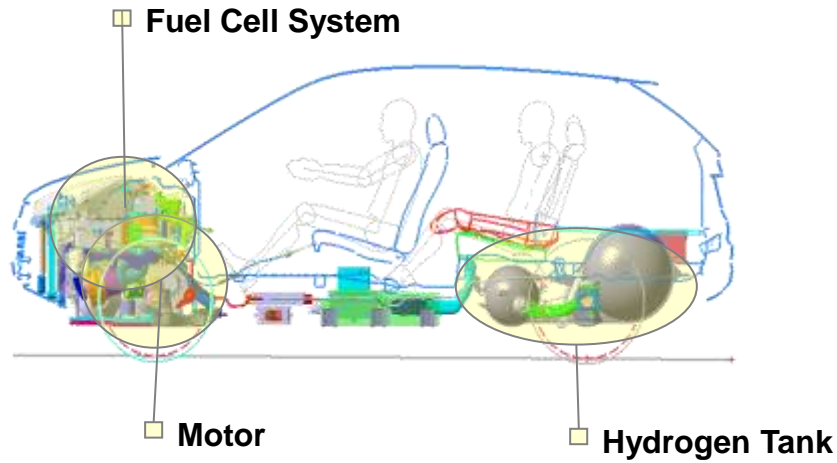


Fuel Cell Power	100 kW
Aux. Power	Supercap. (10F)
Motor System	100 kW
H <sub>2</sub> Tank	3.6 kg H <sub>2</sub> @ 350 bar
Fuel Efficiency (FTP mode)	26.2 km/l
Driving Range	400 km
Acceleration (0 → 100kph)	12.0 sec
Max. Speed	150 KPH

# Tucson iX FCV (2010)

PEMFC-FCV

- Simpler Module Design of Fuel Cell System for Volume Production
- Drastic Cost Reduction by Metallic Bipolar Plate, AC Induction Motor, and Li-ion Battery
- Improve Vehicle Performance for Fleet & General Public Customers



Fuel Cell Power	100 kW
Battery	21 kW
Motor System	AC Induction 100 kW
H <sub>2</sub> Tank	700 bar
Fuel Economy	31 km/l
Driving Range	> 650 km
Acceleration (0 → 100kph)	12.9 sec
Max. Speed	160 KPH

# Fuel Cell Buses

PEMFC-FCV

## ■ FC Bus – 1<sup>st</sup> Generation (2006)





Fuel Cell Power	<b>160 kW</b>
Super Capacity	<b>MAX. 240 kW</b>
Motor System	<b>240 kW</b>
H <sub>2</sub> Tank	<b>40kg H<sub>2</sub> @ 350 bar</b>
Acceleration (0 -> 50kph)	<b>14.2 sec</b>
Max. Speed	<b>72 KPH</b>



## ■ FC Bus – 2<sup>nd</sup> Generation (2009)



Fuel Cell Power	<b>200 kW</b>
Super Capacity	<b>MAX. 400 kW</b>
Motor System	<b>300 kW</b>
H <sub>2</sub> Tank	<b>30kg H<sub>2</sub> @ 350 bar</b>
Acceleration (0 -> 50kph)	<b>8.4 sec</b>
Max. Speed	<b>100 KPH</b>

# Hydrogen Safety Tests

	Gasoline Vehicle	FCEV with Type 3 Tank
<b>Test Condition</b>	<ul style="list-style-type: none"> <li>• Fire initiated from the ashtray</li> </ul>	
<b>Result</b>	<ul style="list-style-type: none"> <li>• Fuel tank exploded after 40 minute.</li> </ul>	<ul style="list-style-type: none"> <li>• PRD activated after 22 minutes.</li> </ul>
<b>Vehicle</b>		

	CNG Tank (150bar)	Hydrogen Tank (350bar)
<b>Test Condition</b>	<ul style="list-style-type: none"> <li>• Fire Source: LPG gas</li> </ul>	
<b>Result</b>	<ul style="list-style-type: none"> <li>• PRD activated : CNG vent</li> <li>• max. flame height 11m</li> </ul>	<ul style="list-style-type: none"> <li>• PRD activated : H<sub>2</sub> vent</li> <li>• max. flame height 8m</li> </ul>
<b>Vehicle</b>		

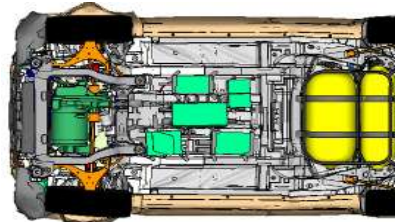


# Fuel Cell Vehicles Tests

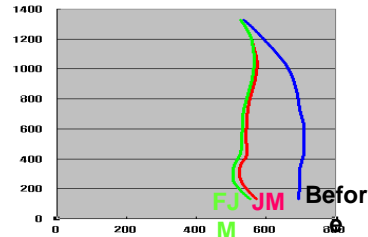
## FCV Collision Analysis

### Front Crash

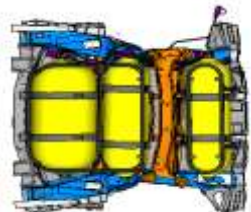
Image courtesy of International Council on Clean Transportation (ICCT) <http://www.icct.org/>



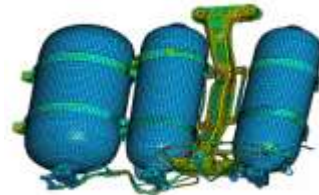
### Side Crash



### Rear Crash



30 MPH



## FCV Collision Test

- Hydrogen Tanks filled with 30 bar Helium during Collision Test
- No Hydrogen leak confirmed by filling 350 bar Hydrogen after Collision



Rear Collision (30 MPH)

# Status of Domestic Fleet Program

1. Period : 2006. 8 ~ 2009. 7 (3 years)

2. Vehicles : 30 Passenger cars, 4 Buses

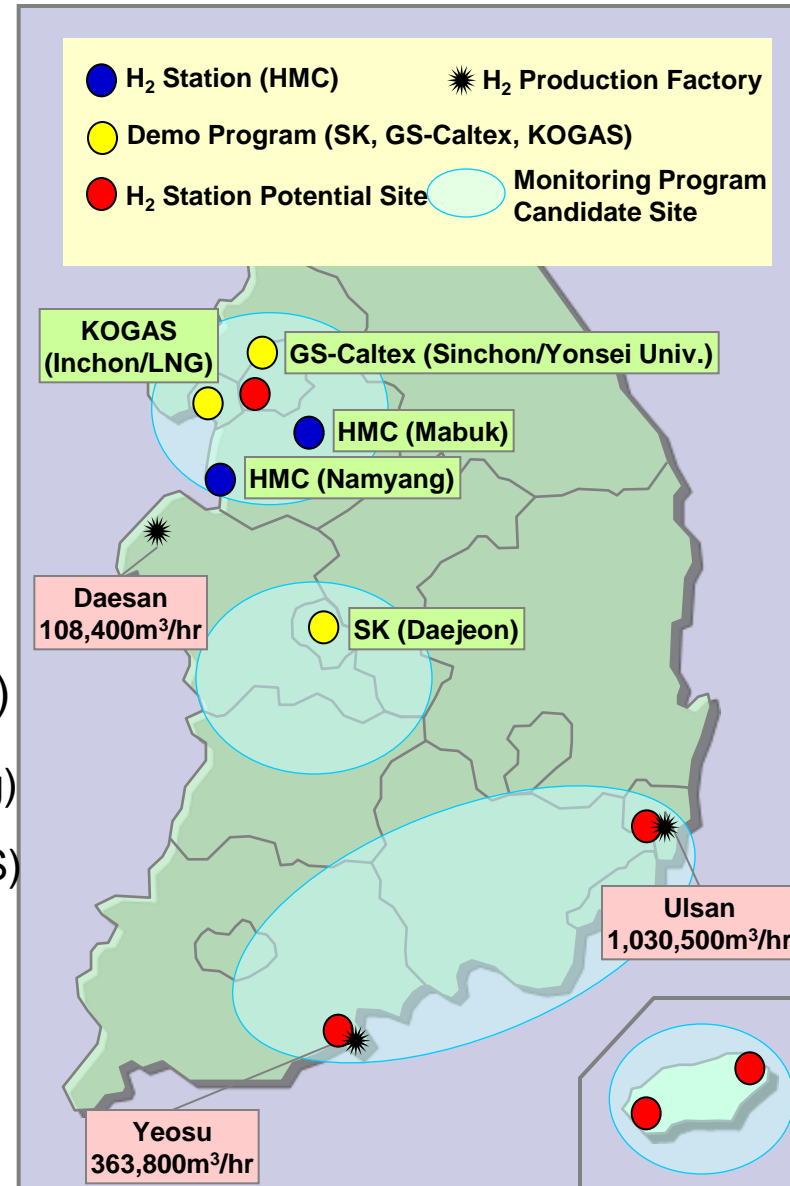
Year	Passenger car	Bus	Station
1 <sup>st</sup>	4	1	2
2 <sup>nd</sup>	8	1	2
3 <sup>rd</sup>	18	2	1



3. Hydrogen Fueling Station : 10 (5 new stations)

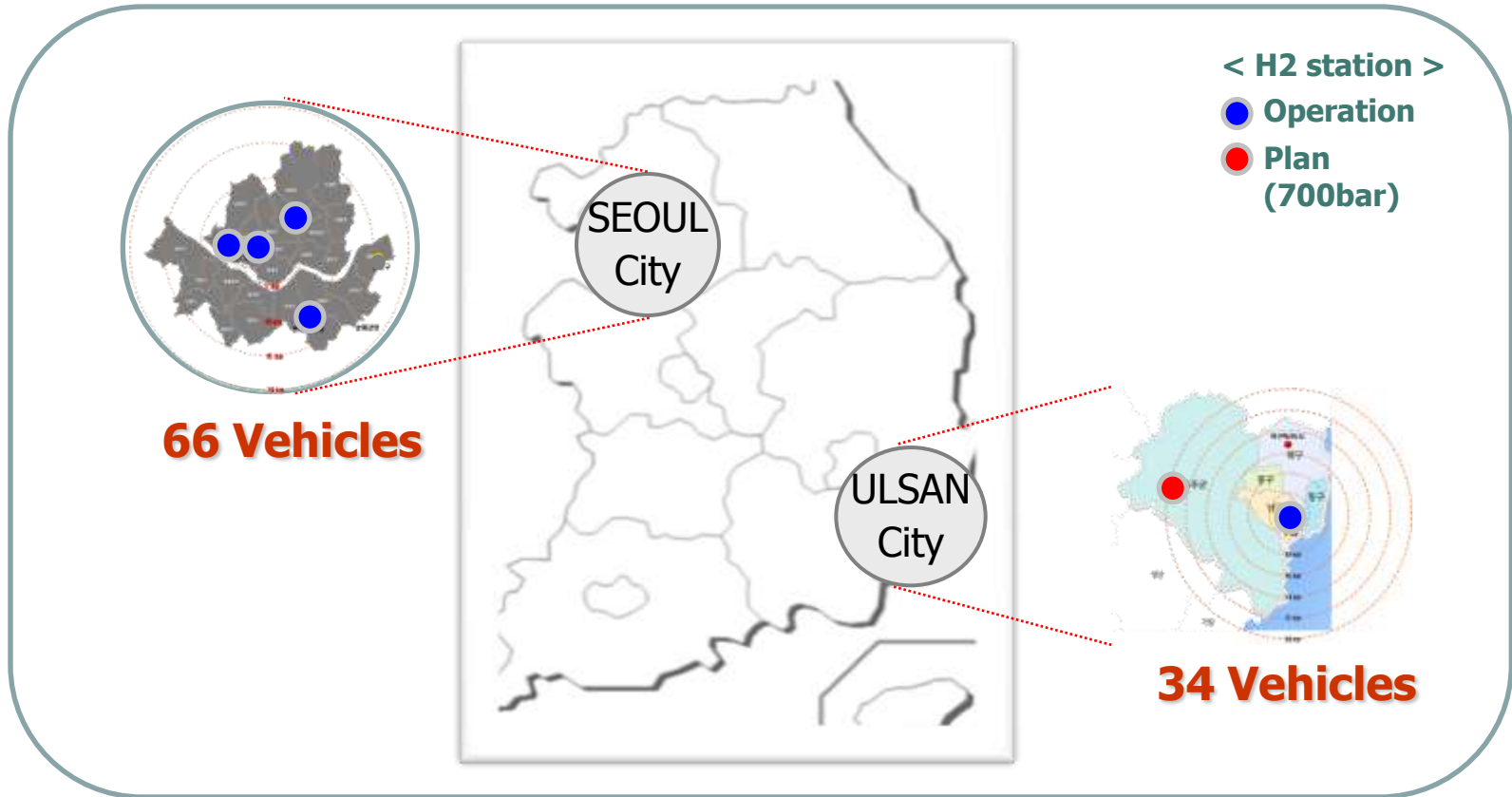
- Hyundai•Kia Motors : 2 stations (Mabuk, Namyang)
- Demo Program 3 stations (SK, GS-Caltex, KOGAS)
- 5 new stations (Seoul 1, Cheju 2, Kyungnam 1, Chunnam 1)

4. Operation Sites : On the map



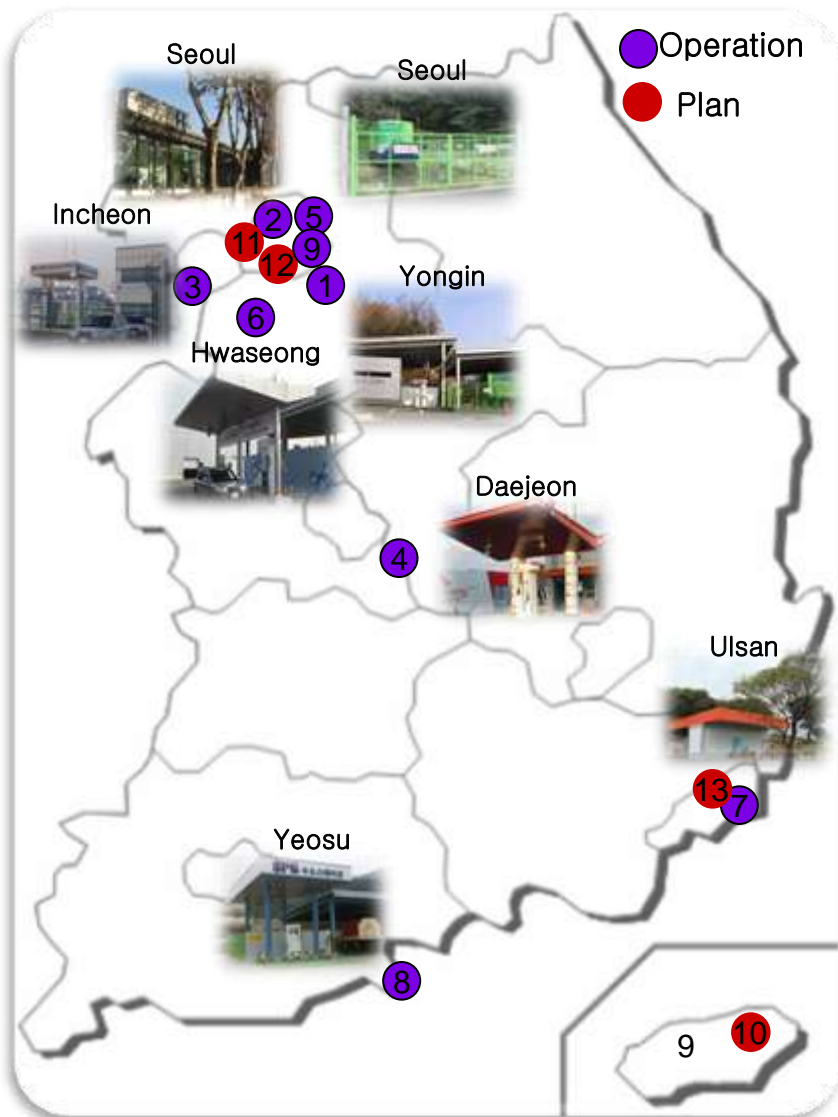
# Domestic Fleet Program (2<sup>nd</sup> Stage)

- 100 Vehicles in the hands of restricted customers
  - 10 vehicles to the lucky general public
- Launched in December, 2009 (SEOUL, ULSAN)

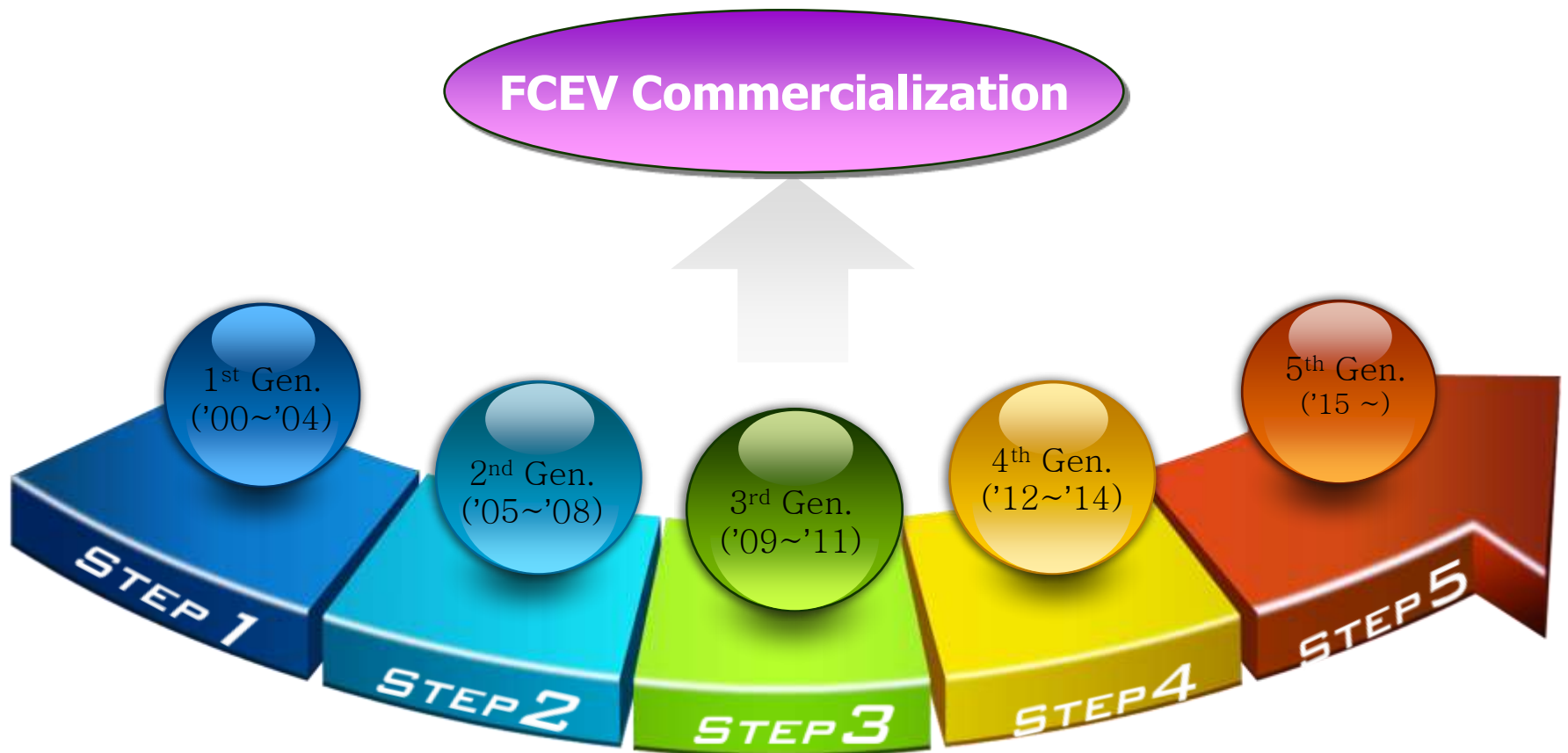


# Building Hydrogen Stations

■ 9 Stations in Operation, 13 Stations by 2011



#	City	Installer	Year	Type	Pressure	Project
1	Yongin	HMC	2005	Truck In	350/700 bar	-
2	Seoul	GS-Caltex	2007	Naphtha reforming	350 bar	H <sub>2</sub> station demonstration
3	Incheon	KOGAS	2007	NG reforming	350 bar	↑
4	Daejeon	SK Energy	2007	LPG reforming	350 bar	H <sub>2</sub> station development
5	Seoul	KIST	2008	Mobile	350 bar	FCEV Fleet
6	Hwaseong	HMC	2008	Truck In	350/700 bar	-
7	Ulsan	Dongdeok Gas	2009	↑	350 bar	FCEV Fleet
8	Yeosu	SPG Chemical	2009	↑	350 bar	FCEV Fleet
9	Seoul	HMC	2009	Mobile	350 bar	2 <sup>nd</sup> FCEV Fleet
10	Jeju	HMC	2010	Electrolysis	350 bar	FCEV Fleet
11	Seoul	HMC	2010	Truck In	350 bar	FCEV Fleet
12	Seoul	City of Seoul	2009	Landfill gas reforming	350 bar	-
13	Ulsan	Dongdeok Gas	2011	Truck In	700bar	2 <sup>nd</sup> FCEV Fleet

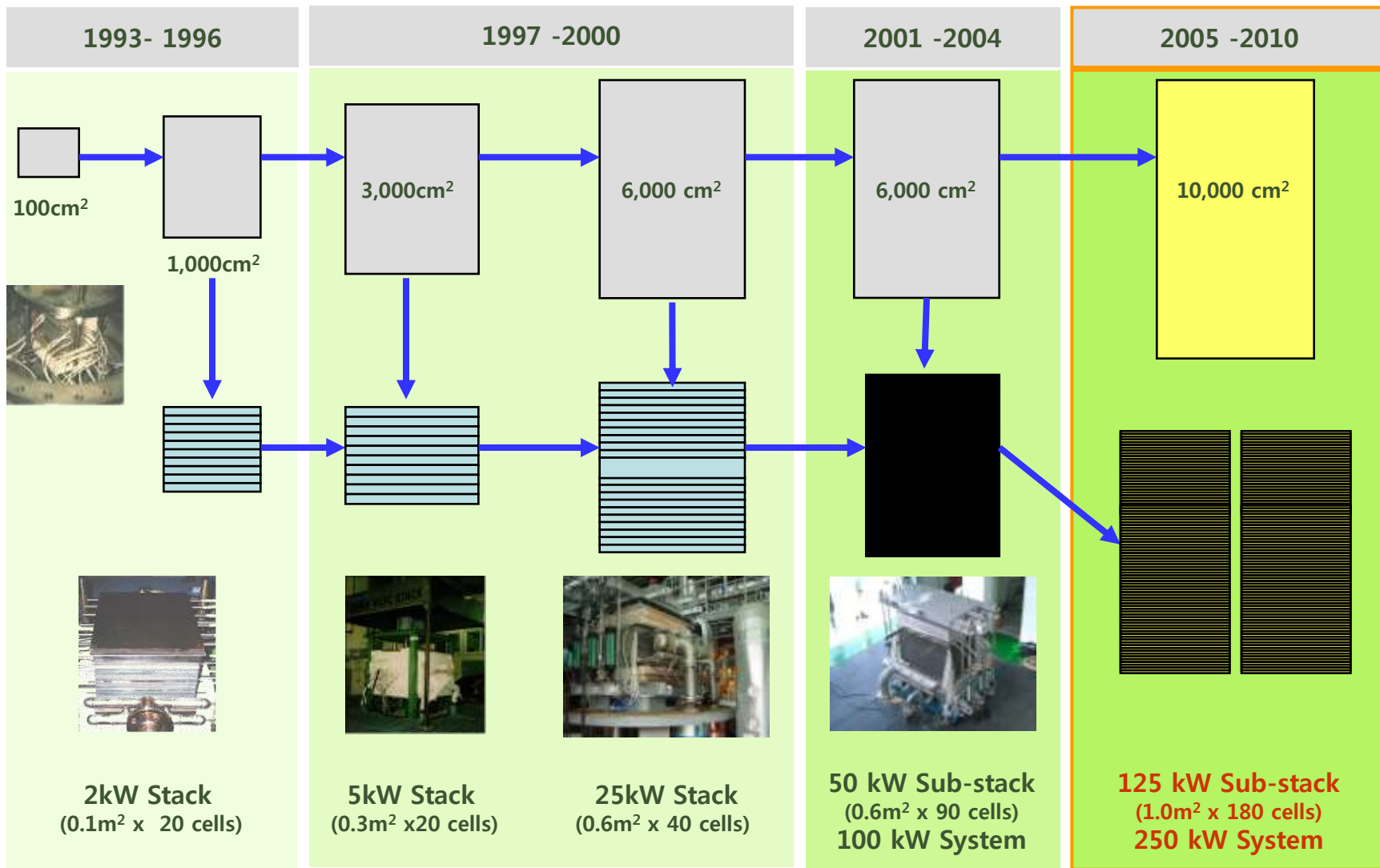


- |  |   |   |   |   |
|--|---|---|---|---|
| <ul style="list-style-type: none"> <li>• Core Technology Development</li> <li>• Outsourced Stack - 1<sup>st</sup> FCV</li> </ul> | <ul style="list-style-type: none"> <li>• System Technology Development &amp; Fleet Operation</li> <li>• Hyundai's Stack - Graphite BP</li> <li>• Tens of FCVs/year</li> </ul> | <ul style="list-style-type: none"> <li>• Semi-Automatic Production</li> <li>• Hyundai's Stack - Metallic BP</li> <li>• Hundreds of FCVs/year</li> </ul> | <ul style="list-style-type: none"> <li>• Pre-commercial Production (Pilot-scale)</li> <li>• <b>1,000 FCVs/year</b></li> </ul> | <ul style="list-style-type: none"> <li>• Commercial Production - Initial Market</li> <li>• <b>10,000 FCVs/year</b></li> </ul> |
|--|---|---|---|---|

Several FCVs/year



## History of Development







**Stacking**

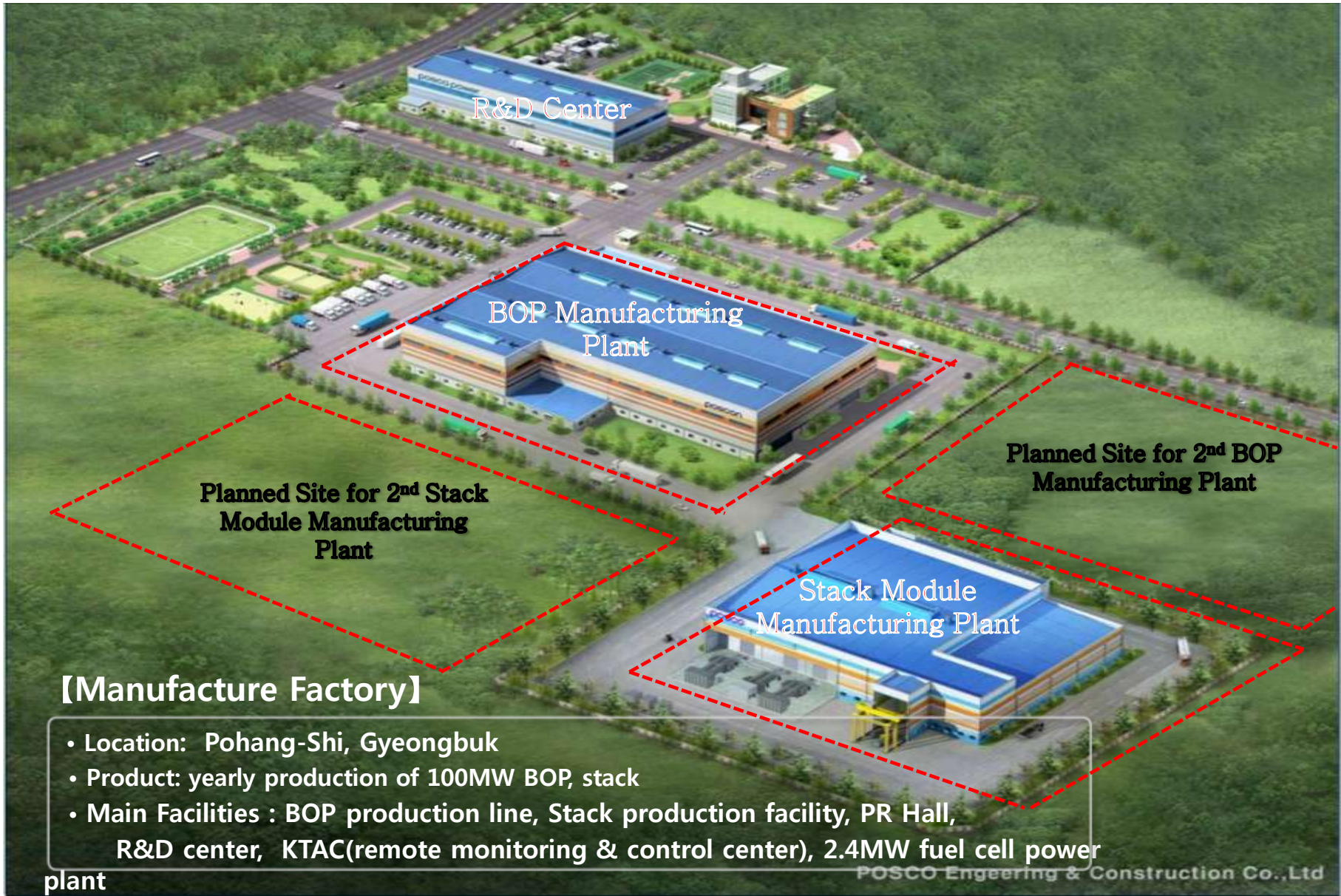


**125kW Unit Stack**



**125kW System**





## 【Manufacture Factory】

- Location: Pohang-Shi, Gyeongbuk
- Product: yearly production of 100MW BOP, stack
- Main Facilities : BOP production line, Stack production facility, PR Hall, R&D center, KTAC(remote monitoring & control center), 2.4MW fuel cell power

plant

## Marketing Status

○ Huge potential identified – Utility, IPP, Local Government, Construction Companies

- on Operation ('06 ~ '10) : 23.7 MW
- under Construction : 16.4 MW

○ Remote Monitoring & Control Center

- established on April 2009
- stable operation and control of FC power plants nation-wide

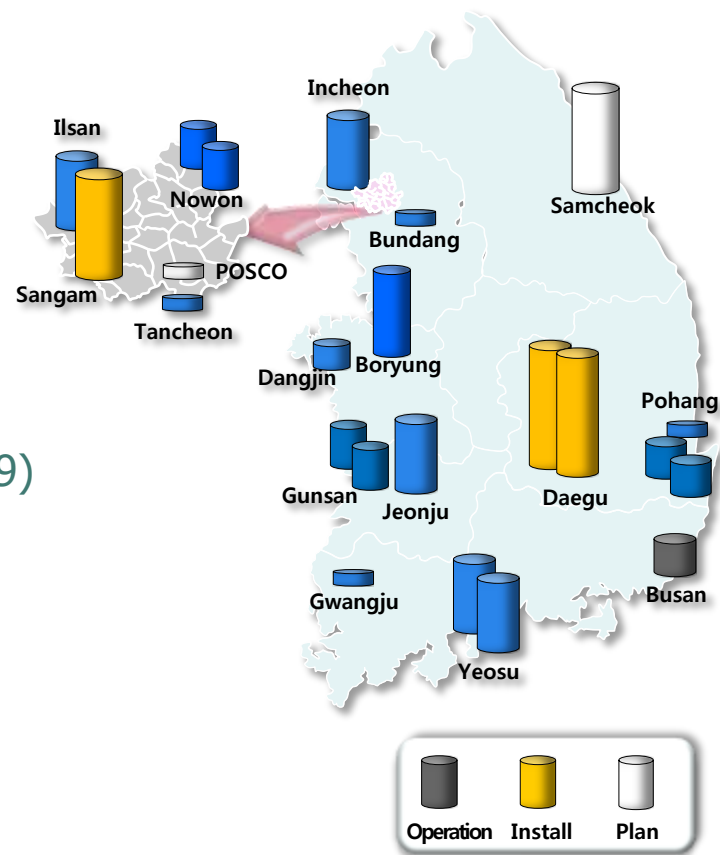
○ CDM Methodology for Fuel Cell Power Plant (May 2009)

○ Respond to forthcoming RPS

- localization, mass production, quality improvement
- to expand manufacturing capacity: 150MW/yr → 500MW/yr

○ FC for Metropolitan City

- Seoul City(capital of KR) completed 2.4MW FC Power Plant → Reference to other cities
- Expansion Plan: Seoul Newtown(20MW), Incheon Songdo(30MW), Sejong City(40MW)





# Components Fabrication Facilities

DooSan Heavy Industries



**Mesh Belt Conveyor Type Furnace**



**Tape Caster**



**Ball Mills**



**Powder Pretreatment Systems**

➤ **Wet-based components fabrication facilities has completely constructed(5MW/yrs).**

# Technology Stack Test Facilities

DooSan Heavy Industries



- **Stack Test Facilities can test performance of two sub-MW stacks simultaneously.**
- **A sub-MW stack test station has installed and has been tested, and the stack is operating.**

# 300kW Prototype BOP

DooSan Heavy Industries



**300kW Prototype BOP Assembly**



**Blower**



**Startup Heater**



**Heat exchanger**



**Water treatment**



**Vaporizer**

## **Equipment List**

- Reactor vessel
- High temp. blower
- Vaporizer
- Heat exchanger
- Start up heater
- Water treatment
- HVAC
- PCS



# DOOSAN Fuel Cell Product Roadmap

2004-06

Material R&D

2007-08

25 kW Stack R&D

2009-11

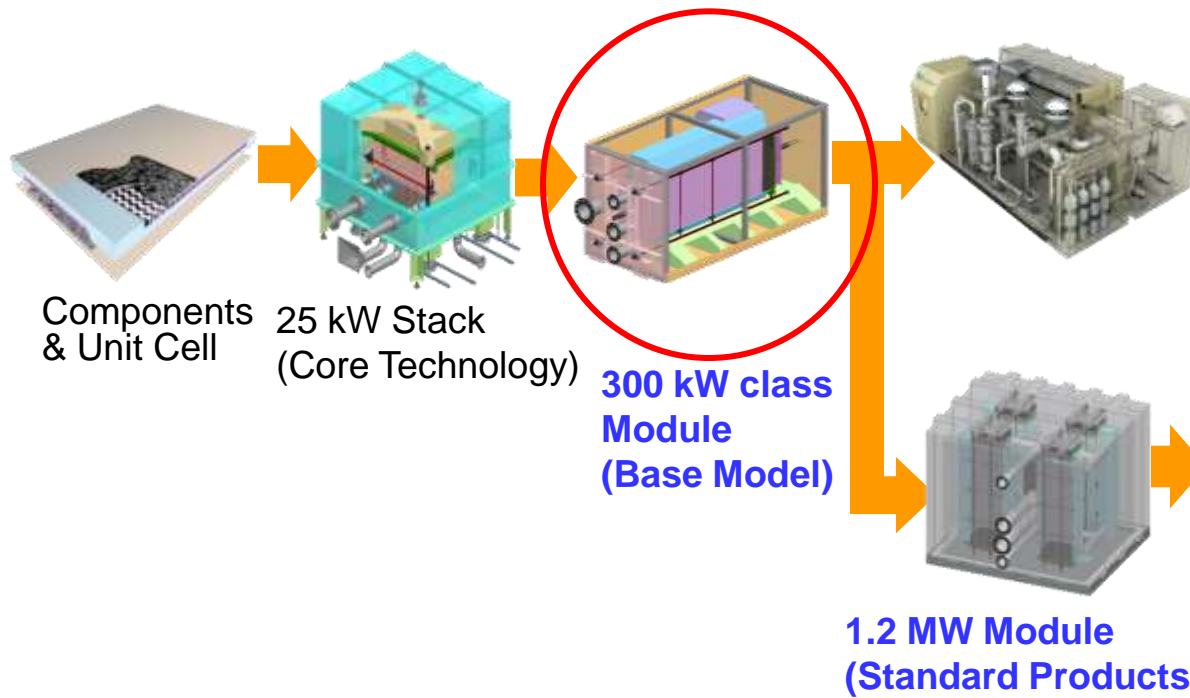
300 kW System

2011-13

MW Class Module

2013-17

MCFC Hybrid Plants



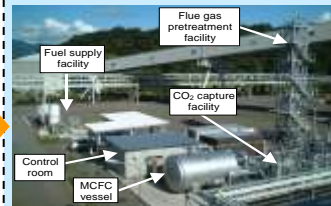
**300 kW class**

Distributed Power (by 2011 )

*Derivative Products*



**Propulsion and auxiliary power for Marine Applications**



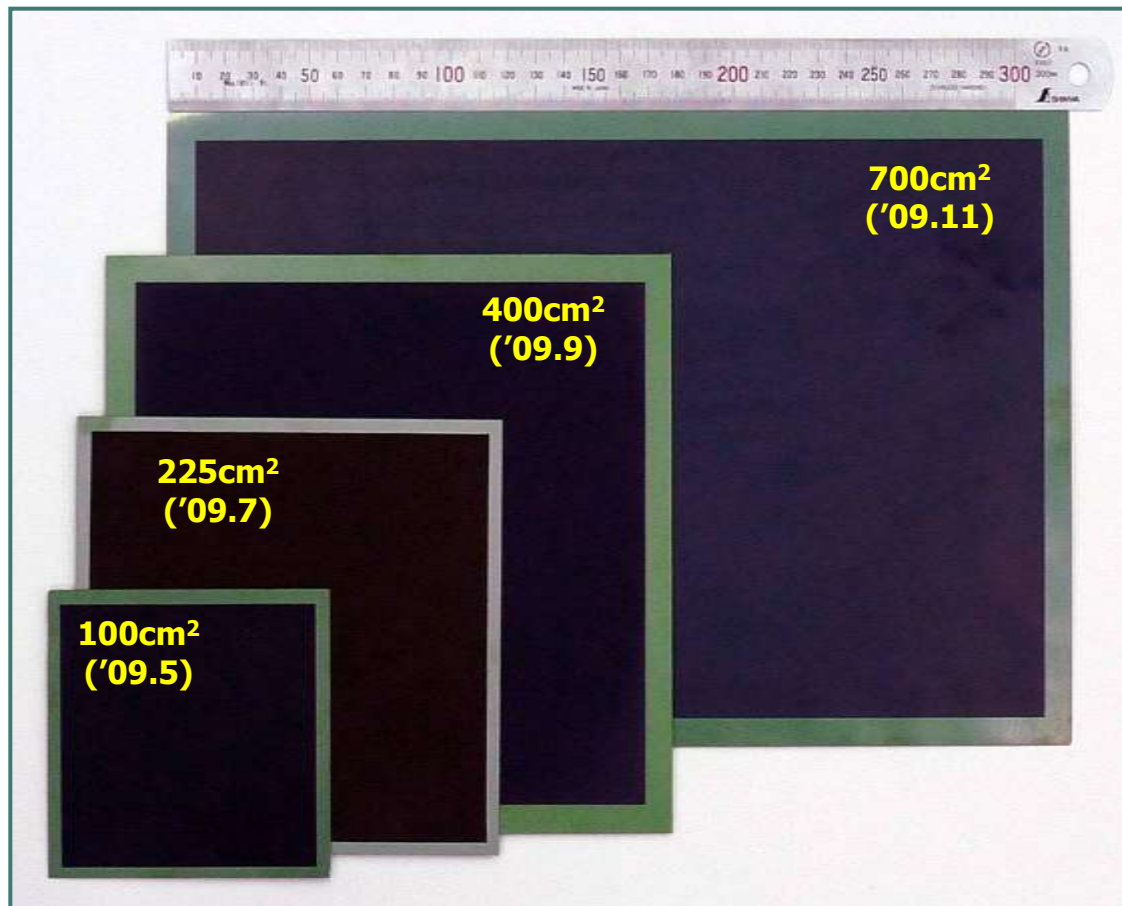
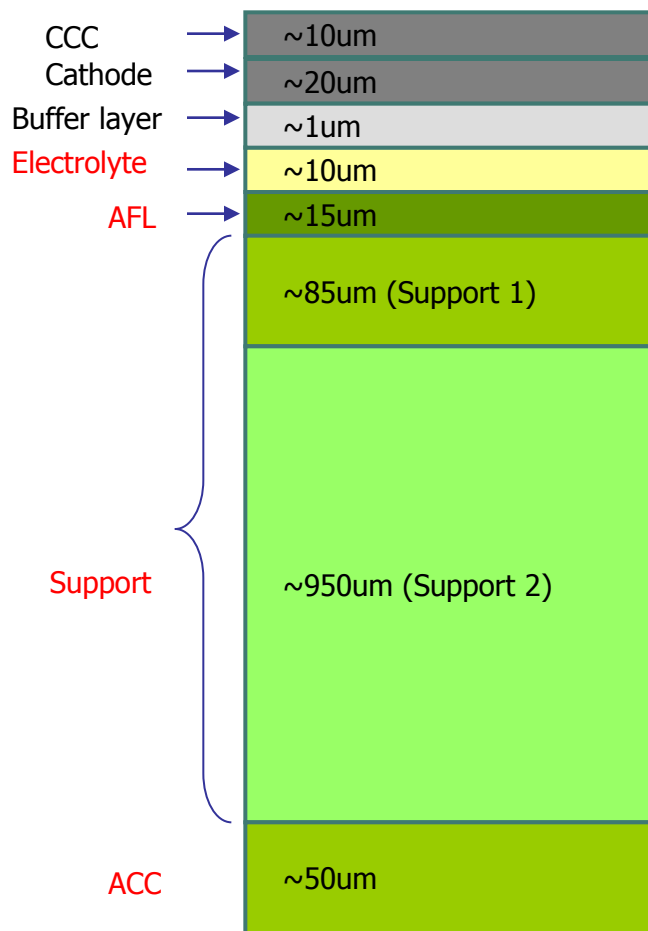
**Multi-MW class Applications for CO<sub>2</sub> Capture & Desalination**



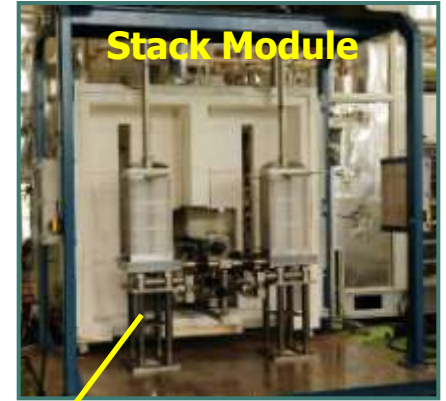
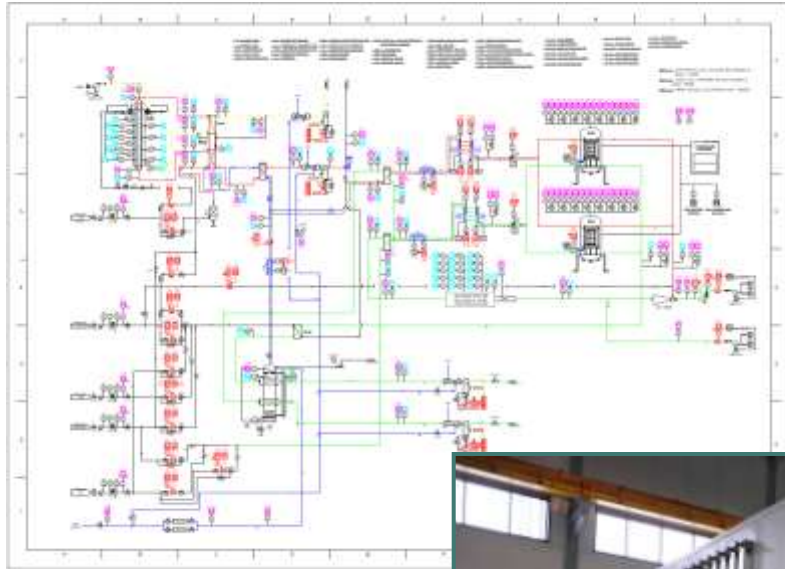
**MCFC- HRSG with System Commonality**



**MCFC- GT Hybrid System**



- ❑ R-Cells: Anode Supported Planar Cells, 1.1mm thick → 0.75mm thick
- ❑ Cell Portfolio: 100cm<sup>2</sup>(10X10), 225cm<sup>2</sup>(15X15), 400cm<sup>2</sup>(20X20), 700cm<sup>2</sup>(22X32), 1,100cm<sup>2</sup>
- ❑ R700: 22X32cm<sup>2</sup>, Active Area 600cm<sup>2</sup>, Nominal power 200W @0.85V, 0.4mA/cm<sup>2</sup>



**Pilot System (25~50kW)**



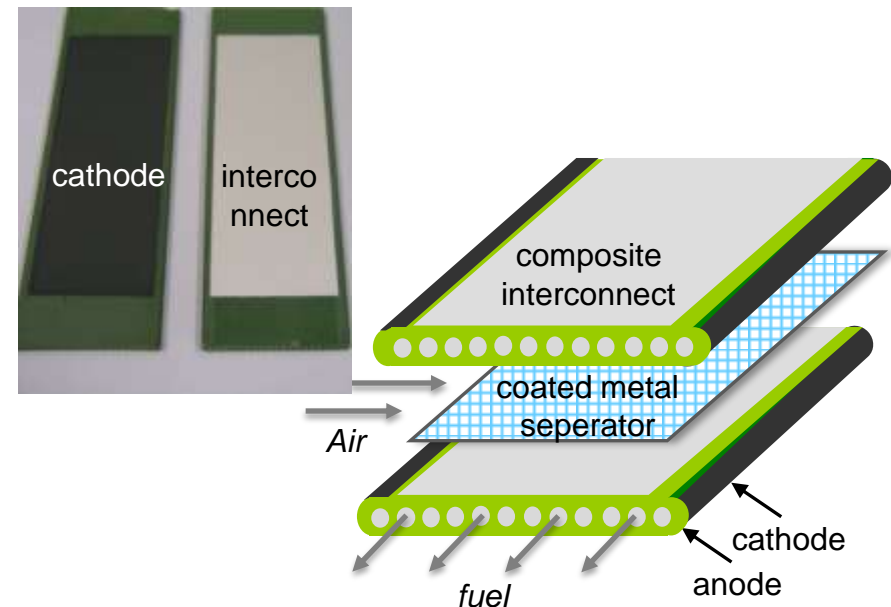
❑ 1998, Development of anode-supported tubular SOFC

- Low temperature operation
- High mechanical strength



❑ 2002, Development of anode-supported flat tube SOFC

- High power density: 0.5 W/cm<sup>2</sup> at 650 °C
- Low temperature operation
- High mechanical strength







Pressurized SOFC for Combined Cycle



1kW Flat tube SOFC

Core technology for 100 kW Tubular SOFC with Samsung

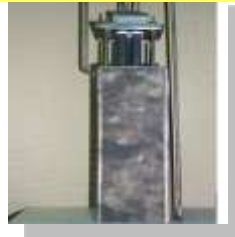
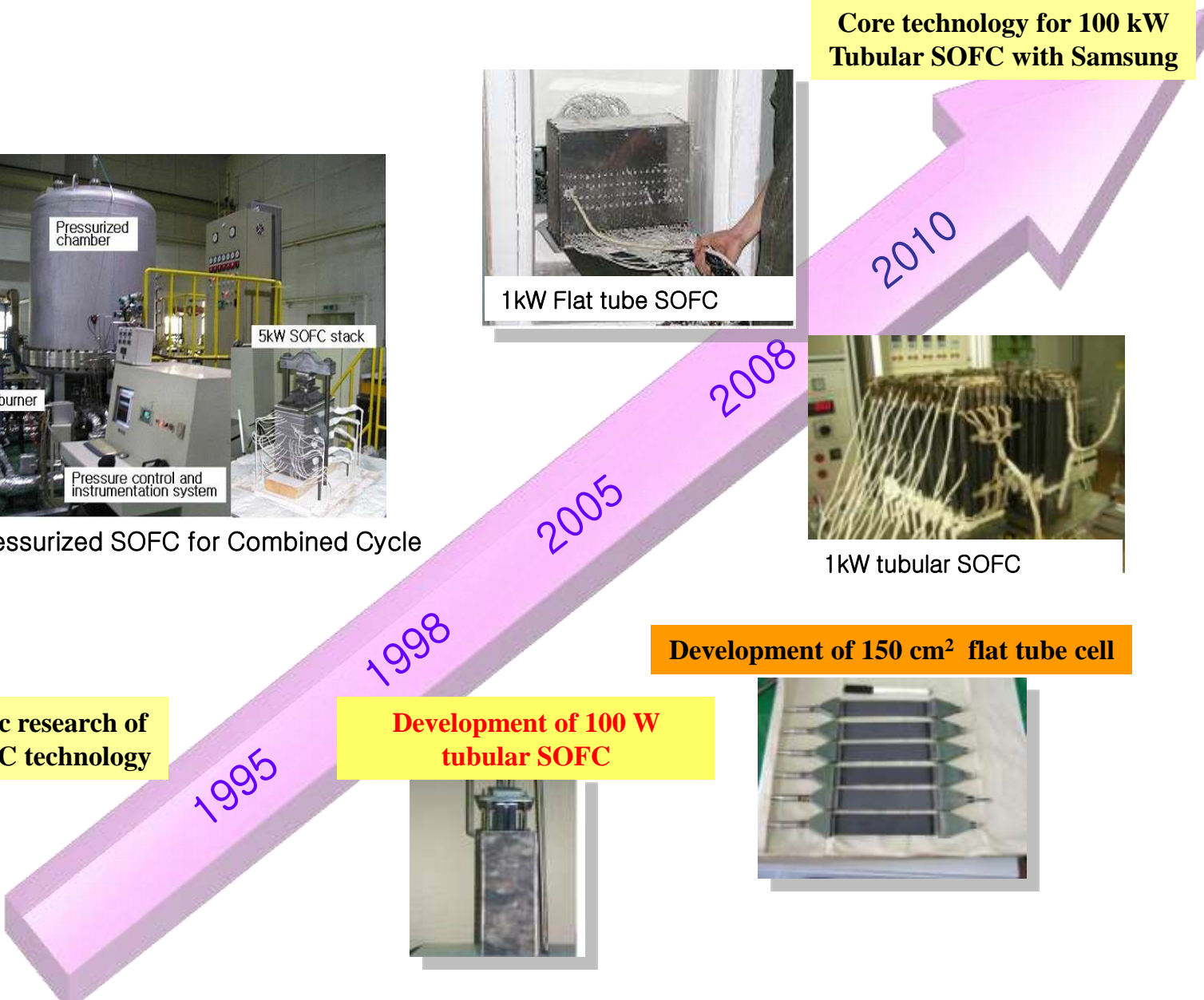


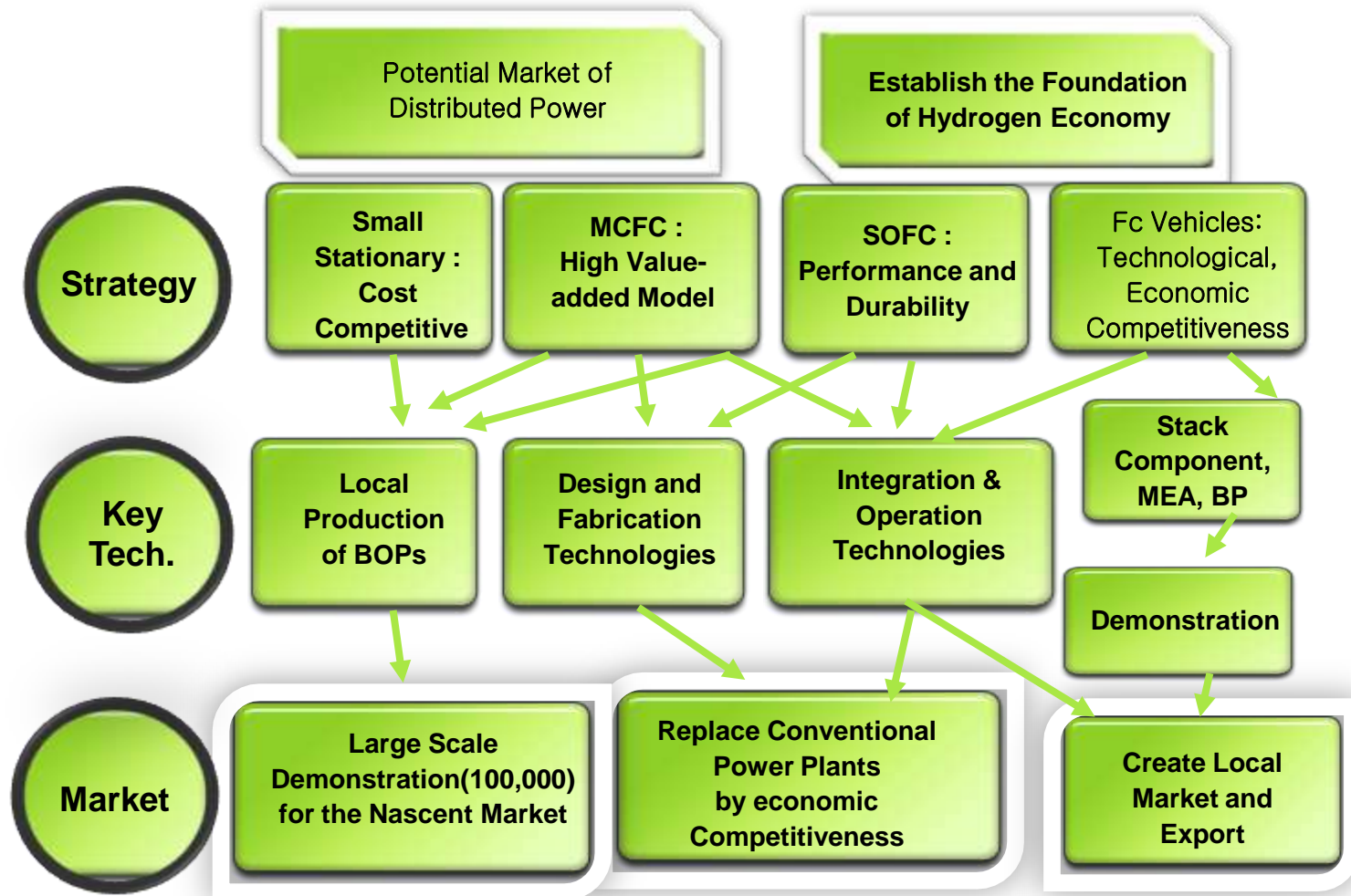
1kW tubular SOFC

Basic research of SOFC technology

Development of 100 W tubular SOFC

Development of 150 cm<sup>2</sup> flat tube cell





- **Small Stationary PEFC : Price Competitiveness**
- **MCFC : Lead Global Market by 2013**
- **SOFC : Develop kW('12) to MW System('15)**



# US-DOE Fleet Program

PEMFC-FCV

1. Period : 2004. 12 ~ 2009. 12 (5years)
2. Budget : \$105 million (Consortium, Government 50%)
3. Partners : Chevron Texaco (Hydrogen Filling Station)  
UTCFC (Fuel Cell Stack)  
AC Transit, SCE, US Army, CARB (Fleet Operators)

## 4. Vehicles : 32 Tucson/Sportage FCEVs

## 5. Accomplishments

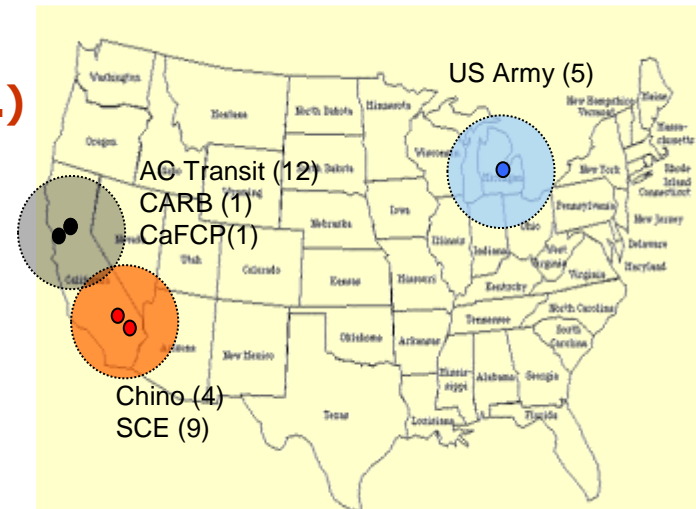
- Total : 868,111 km/21,284hr/71,839 Start up
- Average Fuel Economy: 16.3km/l (gasoline eq.)
- Cold weather drivability proved for 3 years  
in Michigan



1st Vehicle for Demo Fleet Program  
(2005. 12.16)



US Hydrogen Station Completion  
(2005. 2.18)



## ■ New Market Penetration



	Stationary (Stand-alone)	Uninterrupted Power Generation	Ship Propulsion	Large-scaled Fuel Cell
Potential customer	<b>Apartment, Univ., Gov. building</b>	<b>IDC, industrial complex</b>	<b>Shipping company</b>	<b>Utility, IPP</b>
Introducin g factor	<b>Emission reduction within metropolitan city territory</b>	<b>Countermeasure of electricity failure</b>	<b>'16 MARPOL observance (NOx, carbon tax, etc.)</b>	<b>RPS(renewable portfolio standard) District Heating</b>
R&D field	<b>Compact design, load management</b>	<b>Fast load following</b>	<b>Optimization on marine circumstance, fuel conversion, load following</b>	<b>Mass production, high efficiency by turbine combination</b>
R&D period	<b>~ '12</b>	<b>~ '12</b>	<b>~ '15</b>	<b>~ '15</b>

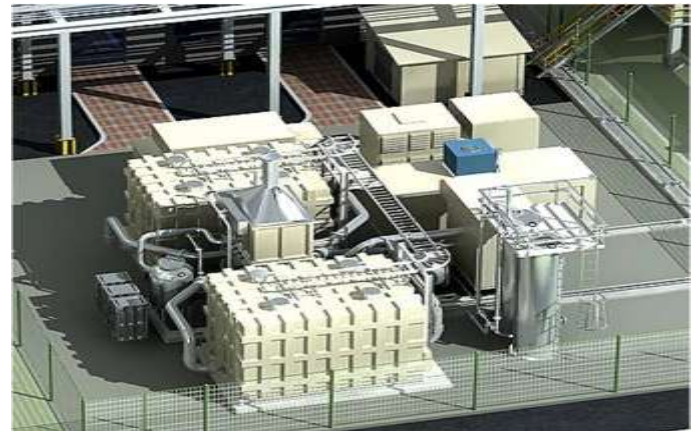
## Selected Installation Sites

<Nowon, 2.4MW (May. '09)>



Localization 22%(Maintenance, Inatallation/Construction)

<Incheon, 2.4MW (November. '09)>



Localization 45% (BOP)

< 20MW ('15)>



Localization 100% (Cell)

<Magok, 10MW ('12)>



Localization 70% (Stack)



# Summary

- **Korea has well organized national R&D plan for hydrogen and fuel cell developments.**
- **The future of hydrogen and fuel cells in Korea is promising.**
- **A steady progress has been made in fuel cell R & D over the years.**
- **A great number of endeavors are made to reach the high-tech society in the government and private sectors through the commercialization of hydrogen and fuel cell.**