



EUROPEAN  
**FUELCELL**  
CONFERENCE

**Roma, December 14 –16, 2005**

# **International Status of Molten Carbonate Fuel Cells**

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# Acknowledgements

The present work has been done with the substantial contribution of colleagues from:

- ❖ FCE, USA
- ❖ GenCell, USA
- ❖ MTU, Germany
- ❖ AFCo, Italy
- ❖ CRIEPI and IHI, Japan
- ❖ KIST and KEPRI, South Korea

To them all our gratitude and my apologise in case we misused the data and the information supplied.

# OUTLINE

- **MCFC Developers in the world and their products**
- **Comparison of solutions and performance**
- **MCFC: where and when to install?**
- **Main factors affecting MCFC commercialization**
- **Achievements**
- **The way ahead**

**The present survey is a summary of the info collection work undertaken for the IEA Agreement on Fuel Cells, Annex 17.**

# MCFC Developers

**The 6 major MCFC industries in the world are:**

- **Fuel Cell Energy, USA**
- **GenCell, USA**
- **MTU CFC Solutions, Germany**
- **Ansaldo Fuel Cells, Italy**
- **KEPCO/POSCO, South Korea**
- **IHI, Japan**

# Fuel Cell Energy (FCE), USA

- Headquartered in Danbury, CT;  
Manufacturing Facilities in Torrington, CT
- 350 Employees
- Going to market now with advanced  
Direct FuelCell® technology
- A leading fuel cell technology developer  
for over 30 years. Over 450 M\$ invested
- Developing high temperature solid oxide  
planar fuel cell technology (Versa)
- NasdaqNM:FCEL



# Fuel Cell Energy (FCE), USA



**DFC300MA**



**DFC1500**



**DFC3000**

FCE has developed three classes of products, named DFC 300, DFC 1500 and DFC 3000. The relative output electric power is, respectively, 250 kW, 1 MW and 2 MW, with an efficiency of about 47-50%. A hybrid MCFC-Gas Turbine system has also been successfully demonstrated.



**Multi-MW Grid Support**

# GenCell, USA

- *GenCell Corporation* is located in Southbury, Connecticut.
- Founded in 2002, through the fusion of Allen Engineering and Fuel Cell Technology.
- 14 Employees

The company is targeting the distributed generation market in the 40 to 125kW range.



# MTU CFC Solutions, Germany

- ◆ Located near Munich / Germany
- ◆ Established January 2003
- ◆ 87 employees
- ◆ Total Area: 11'000 m<sup>2</sup>
- ◆ Power Plant Assembly and Test
- ◆ Pilot Cell Manufacturing



- ◆ 220 kW electrical
- ◆ 180 kW thermal

- ◆ Elect. efficiency: 47%
- ◆ Total efficiency: > 90 %

MTU's product is the **HOTMODULE®**, a system for tri-generation, based on FCE's fuel cells.

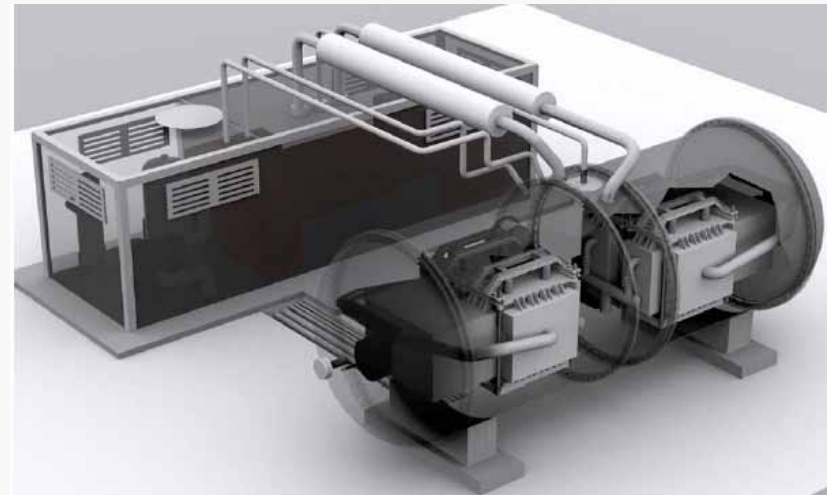
# Ansaldo Fuel Cells, Italy



- Headquartered in Genoa; Manufacturing Facilities in Terni
- Part of the Finmeccanica Group, was funded in December 2001, to continue the work carried out by Ansaldo Ricerche
- 70 Employees

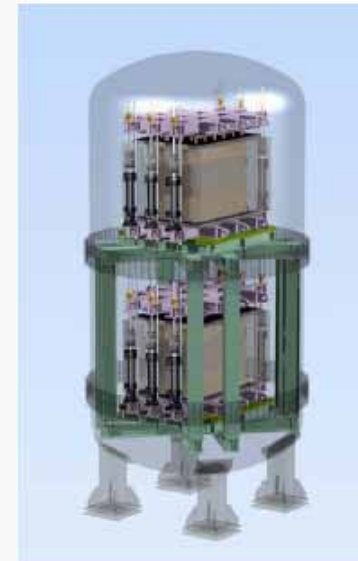
AFCo is developing systems in the 500 kW-5 MW range.

The building block is the 500 kW Twin Stack®



# KEPRI/POSCO, South Korea

- KEPRI, formerly the Electricity Laboratory of KEPCO, was established in July, 1961.
- With more than 40 years of experiences, KEPRI has been leading the Korean national electrical technology development
- POSCO is one of the top steel company in the world
- About 30.000 employees
- POSCO and KEPRI are the main contractors for MCFC power plants realizations



# IHI, Japan

- IHI (Ishikawajima-Harima Heavy Industries) Co.,Ltd has about 7300 employees
- Has developed MCFC power systems from 10 kW to 300 kW class
- The final goal is to replace large-size thermal power plants
- Short/ Mid-term goal is to operate a 7MW hybrid system MCFC/GT



# Comparison of Solutions and Performance

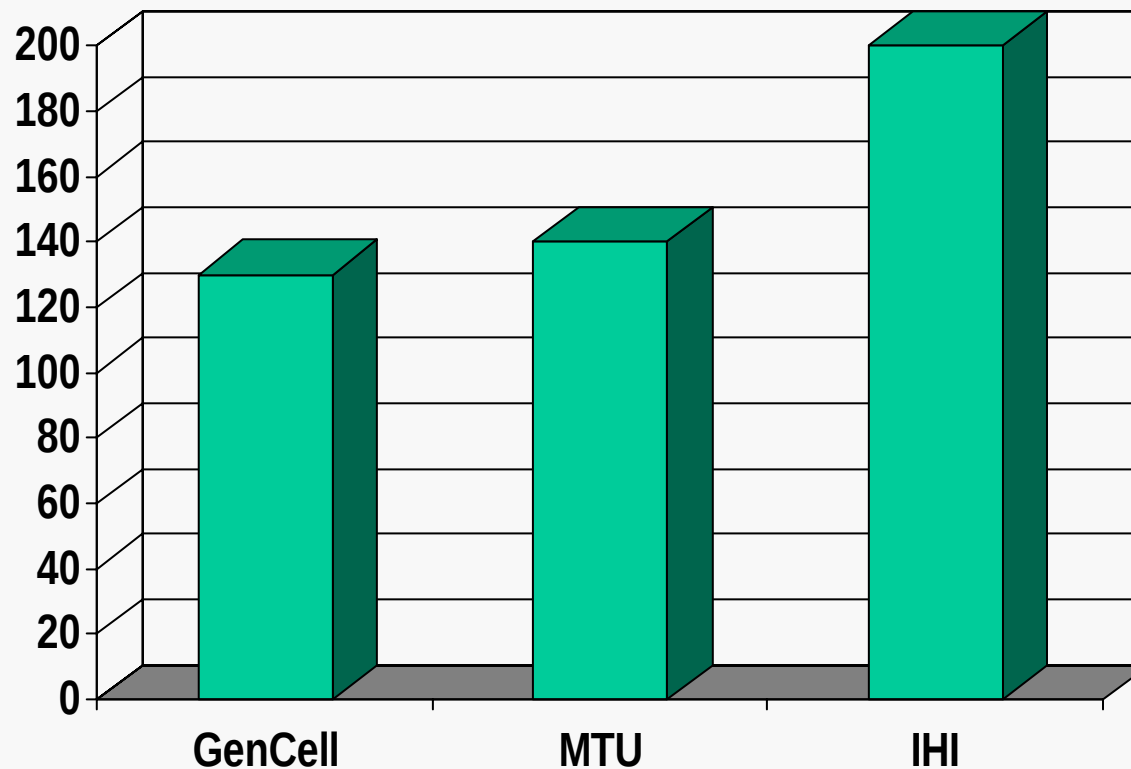
|                                | <b>FCE</b>                                                        | <b>GenCell</b>                                                  | <b>MTU</b>                  | <b>AFCo</b>         | <b>IHI</b>             | <b>KEPRI</b> |
|--------------------------------|-------------------------------------------------------------------|-----------------------------------------------------------------|-----------------------------|---------------------|------------------------|--------------|
| <b>Main Focus</b>              | (250kW)<br>MW (1, 2, and<br>multi MWs)                            | 40-120 kW                                                       | 250 kW                      | 500 kW-<br>MW class | 300 kW<br>3-7 MW       | 250 kW       |
| <b>Number of<br/>Employees</b> | 350                                                               | 14                                                              | 85                          | 70                  | NA                     | NA           |
| <b>Manifolding</b>             | External                                                          | Anode – internal<br>Cathode -<br>external                       | External                    | External            | Internal               | Internal     |
| <b>Reforming</b>               | Internal                                                          | Internal, indirect<br>reforming with<br>chamber in each<br>cell | Internal                    | External/<br>MIR    | External               |              |
| <b>Operating<br/>Pressure</b>  | Atmosph                                                           | Atmosph.                                                        | Atmosph.                    | 3.5 bar             | 0.1-1.2<br>MPa         |              |
| <b>Fuels<br/>Tested</b>        | NG, ADG<br>Propane<br>Methanol<br>Coal Gas<br>Diesel<br>Coal Mine | NG                                                              | NG, Sewage<br>Gas, Methanol | NG, H2,<br>Syngas   | NG,<br>Gasssif.<br>gas |              |

## Comparison of Solutions and Performance (2)

|                                             | <b>FCE</b>                       | <b>GenCell</b> | <b>MTU</b> | <b>AFCo</b>             | <b>IHI</b> | <b>KEPRI</b> |
|---------------------------------------------|----------------------------------|----------------|------------|-------------------------|------------|--------------|
| <b>Installed Systems</b>                    | NA                               | 1              | 16         | 3                       | 11         |              |
| <b>Systems operating</b>                    | 40                               | 1              | 10         |                         | 1          |              |
| <b>Ongoing orders/<br/>planned projects</b> | NA                               | 2              | -          | 4                       | 1          |              |
| <b>kW Installed</b>                         | 20.000                           | 40             | 4.000      | NA                      | 2.120      |              |
| <b>kWh delivered</b>                        | 80 million<br>(at customer site) | NA             | 46 million | NA                      | NA         |              |
| <b>Longest operation time (h)</b>           | NA                               | 3.000          | 25.000     | 10.000 (on single cell) | 16.000     | 10.000       |

## Comparison of Solutions and Performance (3)

**Current Density (mA/cm<sup>2</sup>) at 0.7 Volt on Reformate:**



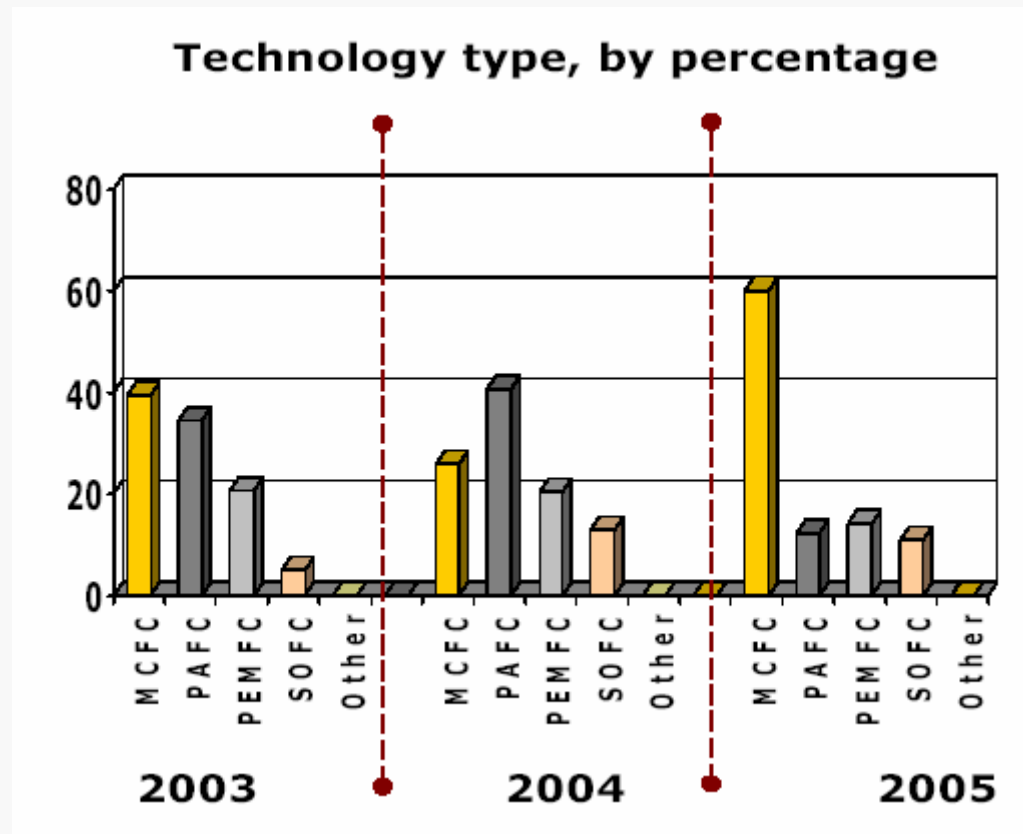
# University and research centers involved in MCFC research

| Country                | University or Research Institute/City                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>USA</b>             | <ol style="list-style-type: none"> <li>1. Illinois Institute of Technology (Selman), IL</li> <li>2. Lawrence Livermore National Laboratory, Livermore, Ca</li> <li>3. South Carolina University, SC</li> <li>4. University of Connecticut, CT</li> </ol>                                                                                                                                                                                                                                                    |
| <b>Japan</b>           | <ol style="list-style-type: none"> <li>1. Yokohama National University, Yokohama-shi</li> <li>2. National Institute of advanced industrial science and technology, Ikeda city, Osaka</li> <li>3. Nisshin Steel Co., Shin-nannyo city, Yamaguchi</li> <li>4. Nagoya University, Chikusa, Nagoya</li> <li>5. CRIEPI</li> <li>6. Japan Fine Ceramics Center, Atsuta-ku, Nagoya</li> <li>7. Kyoto University, Kyoto</li> <li>8. Tohoku University, Aoba ku, Sendai</li> <li>9. Kobe university, Kobe</li> </ol> |
| <b>S. Korea</b>        | <ol style="list-style-type: none"> <li>1. Hanyang University, Seoul</li> <li>2. KEPRI, Yusong-gu, Daejeon</li> <li>3. KIST, Seoul</li> <li>4. Korea University, Seoul (H. Lee)</li> <li>5. Yonsei University, Seoul</li> </ol>                                                                                                                                                                                                                                                                              |
| <b>China</b>           | <ol style="list-style-type: none"> <li>1. Institute of corrosion and protection of metals, Shenyang</li> <li>2. Shanghai Jiaotong University, Shanghai</li> </ol>                                                                                                                                                                                                                                                                                                                                           |
| <b>Italy</b>           | <ol style="list-style-type: none"> <li>1. ENEA, Rome</li> <li>2. University of Perugia, Perugia</li> <li>43. University of Siena, Siena</li> </ol>                                                                                                                                                                                                                                                                                                                                                          |
| <b>Germany</b>         | <ol style="list-style-type: none"> <li>1. Otto-von-Guericke University, Magdeburg</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>France</b>          | <ol style="list-style-type: none"> <li>1. Ecole Nationale Superieire de Chimie de Paris, Paris</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Spain</b>           | <ol style="list-style-type: none"> <li>1. CIEMAT, Madrid</li> <li>2. CSIC, Madrid</li> <li>3. Univ. de Vigo, ETSEI, Vigo</li> </ol>                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Sweden</b>          | <ol style="list-style-type: none"> <li>1. Royal Institute of Technology, Stockholm</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Poland</b>          | <ol style="list-style-type: none"> <li>1. Institute of physical chemistry, Krakow</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>The Netherlands</b> | <ol style="list-style-type: none"> <li>1. Delft University of Technology, Delft</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Denmark</b>         | <ol style="list-style-type: none"> <li>1. Technical University of Denmark</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Romania</b>         | <ol style="list-style-type: none"> <li>1. Polytechnic University of Bucharest</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Turkey</b>          | <ol style="list-style-type: none"> <li>1. Gazi University, Ankara</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                                                |

Courtesy of FCE

# MCFC: Where and When to Install?

For installations of more than 10 kW, MCFC is currently the most employed FC technology:



Source: Fuel Cell Today Market Survey: Large Stationary Applications

## Competitive FC Technologies:

✓PEM: only UTC is developing PEM in the 250 kW range (no installation)

✓SOFC: only S-W tubular demonstrated for 100 kW range

✓PAFC: commercially available 200 kW UTC  
PureCell 200

# MCFC: Where and When to Install?

- King County (DFC1500), Terminal Island (DFC300A), City of Santa Barbara (2 DFC300A)



- Kirin Brewery (DFC300A), City of Fukuoka (DFC300A), Sanitation Districts of LA County (DFC300A)



- Sierra Nevada Brewery Co. (4 DFC300A), Tokyo 'Super Eco Town' (DFC300A)



**FCE WASTEWATER  
TREATMENT AND  
BREWERY**

# MCFC: Where and When to Install?

## ➤ Institutional

- Hospitals
- Universities



## ➤ Commercial

- Hotels
- Data Centers
- Office/Shopping



## ➤ Industrial

- Waste Water
- Telecom
- Food & Beverage
- Chemical
- Manufacturing

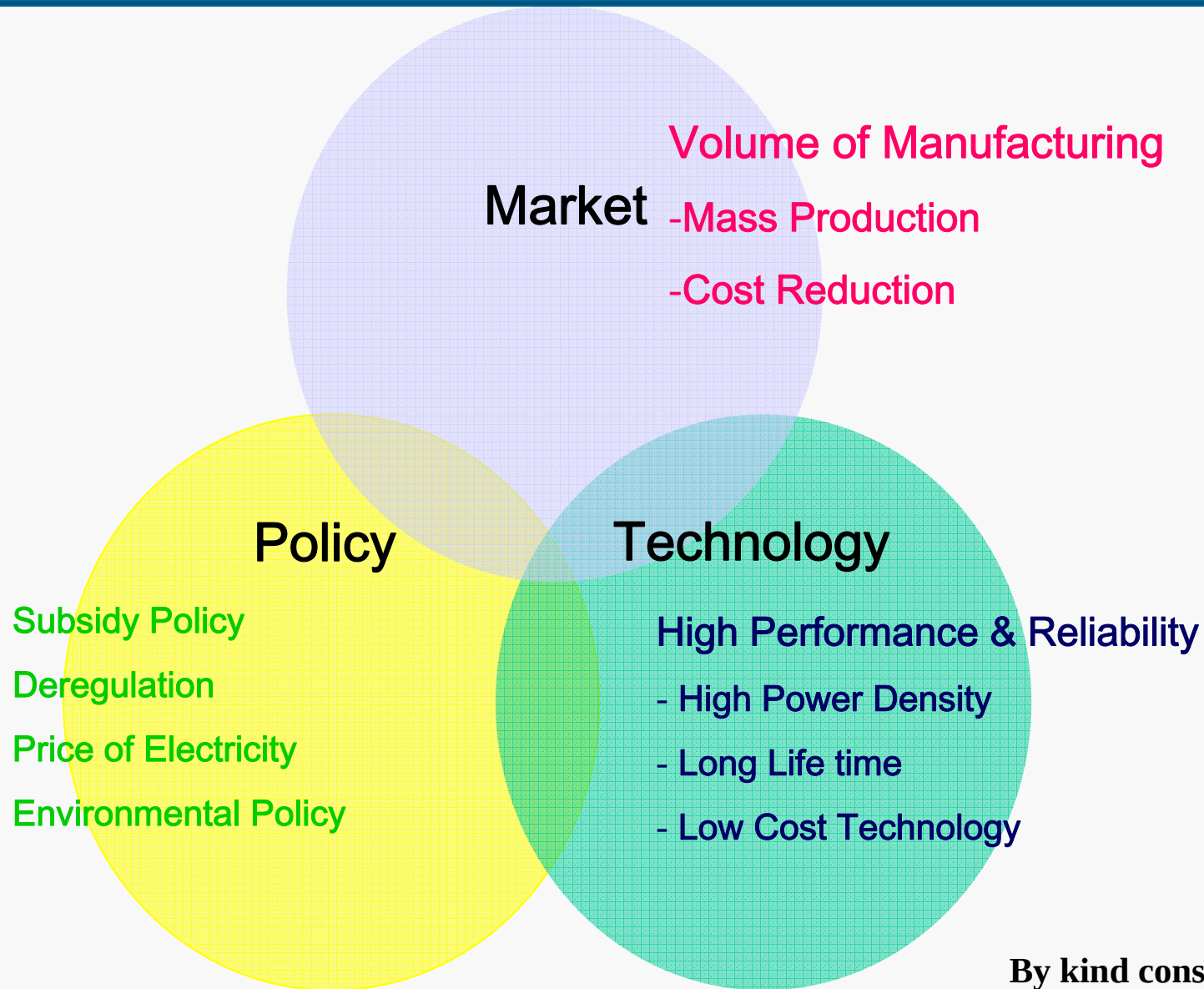


## ➤ Utility

- Grid-support

(Courtesy of FCE)

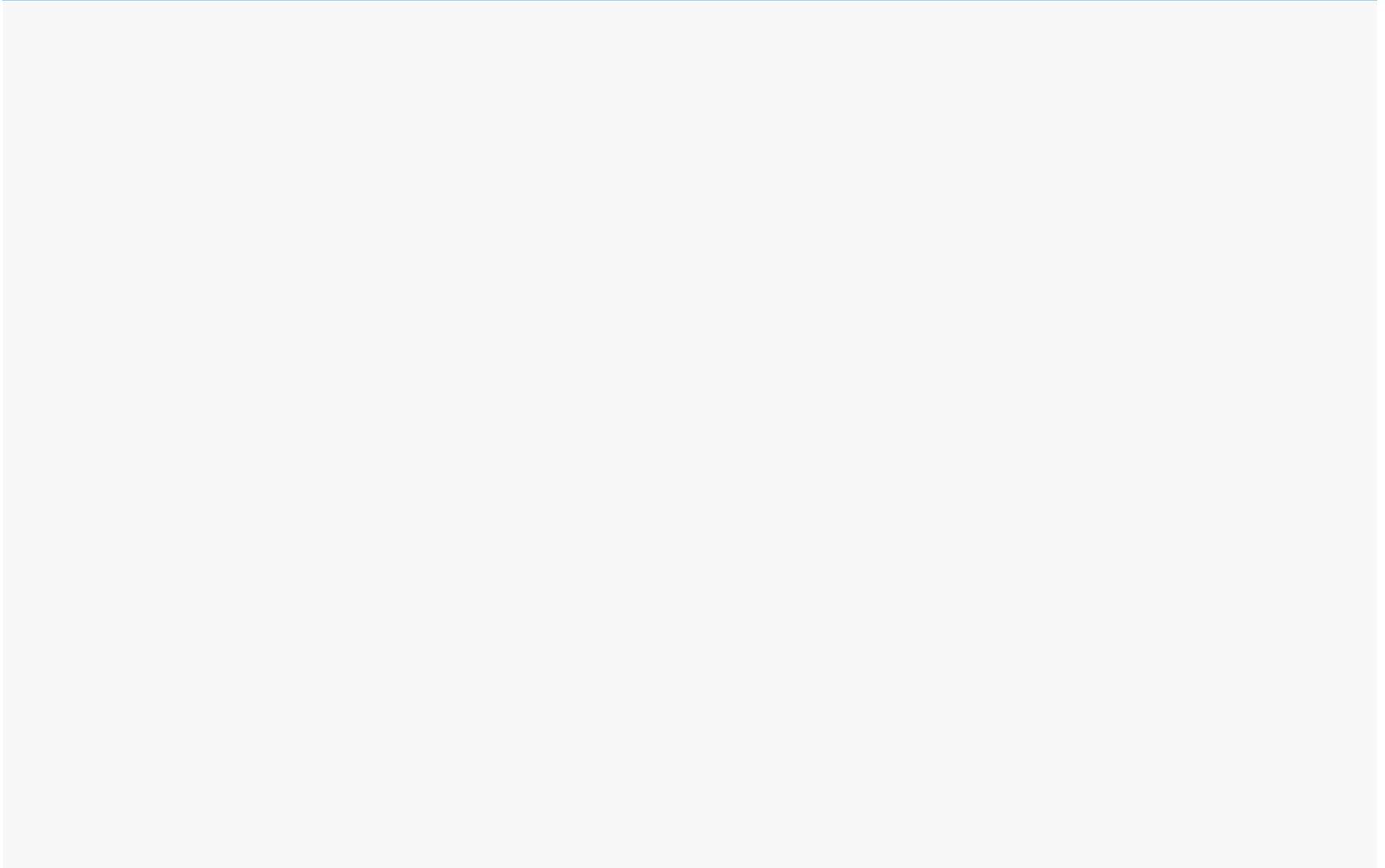
# Main factors affecting MCFC commercialisation



By kind consent of KEPRI

# Main factors affecting MCFC commercialization: technology

- Performance decay (stack life time)
  - Cathode dissolution
  - Electrolyte management
- Reliability
  - According to the demonstration test performed is more related to some BOP components, rather than to the stack itself
- High performance
  - Increase power density
- Low cost technology
  - Improve manufacturing processes, from raw materials to the components of the stack (1/3 of the cost)
  - Simplify BOP and improve its compactness (2/3 of the cost)



# Achievements: FCE

## Fuel Cell Energy / USA

Coast Guard – CHP, barracks  
Sheraton (2) – CHP, hotels  
Ocean County College – CHP, university  
Yale University – CHP, university  
Zoot Enterprises (2) – reliability for critical load  
Harrisburg Coal Mine – power from coal mine emissions  
DFC/T (2) – Vision 21 combined cycle  
Mercedes – power for general load  
LADWP – power for office headquarters  
LADWP – CHP, WWT  
Grand Valley State University – CHP, university  
Navy – land-based marine diesel application  
AMP-Ohio – utility-scale grid support at substation  
CAT Tech Center – grid-connected, training for engineers & dealers  
USCG Cape Cod – CHP,  
Edison – CHP,  
Parsippany – CHP  
Yale - CHP

## MTU / Europe

University of Bielefeld – CHP, hospital  
Rhon-Klinikum – CHP, hospital  
RWE – CHP, energy park  
IZAR – power, ship-builder  
Deutsche Telecom – DC backup, telecom  
EnBW/Michelin – electricity/steam, manufacturing  
IPF Magdeburg – CHP, medical clinic  
Gruenstadt Clinic/Pfalzwerke – CHP, medical clinic  
Bad Berka – CHP, hospital  
Vattenval Europe Berlin – CHP, bi-fuel  
Krefeld (2) 2005 - CHP  
Ahlen 2005 – CHP

## Marubeni / Japan

Kirin Brewery – CHP, industrial WWT  
City of Fukuoka – CHP, municipal WWT  
Nippon Metal – CHP, natural gas  
Epson 1 + 2 - CHP, natural gas  
Japex – CHP, natural gas

## Achievements: **GenCell**

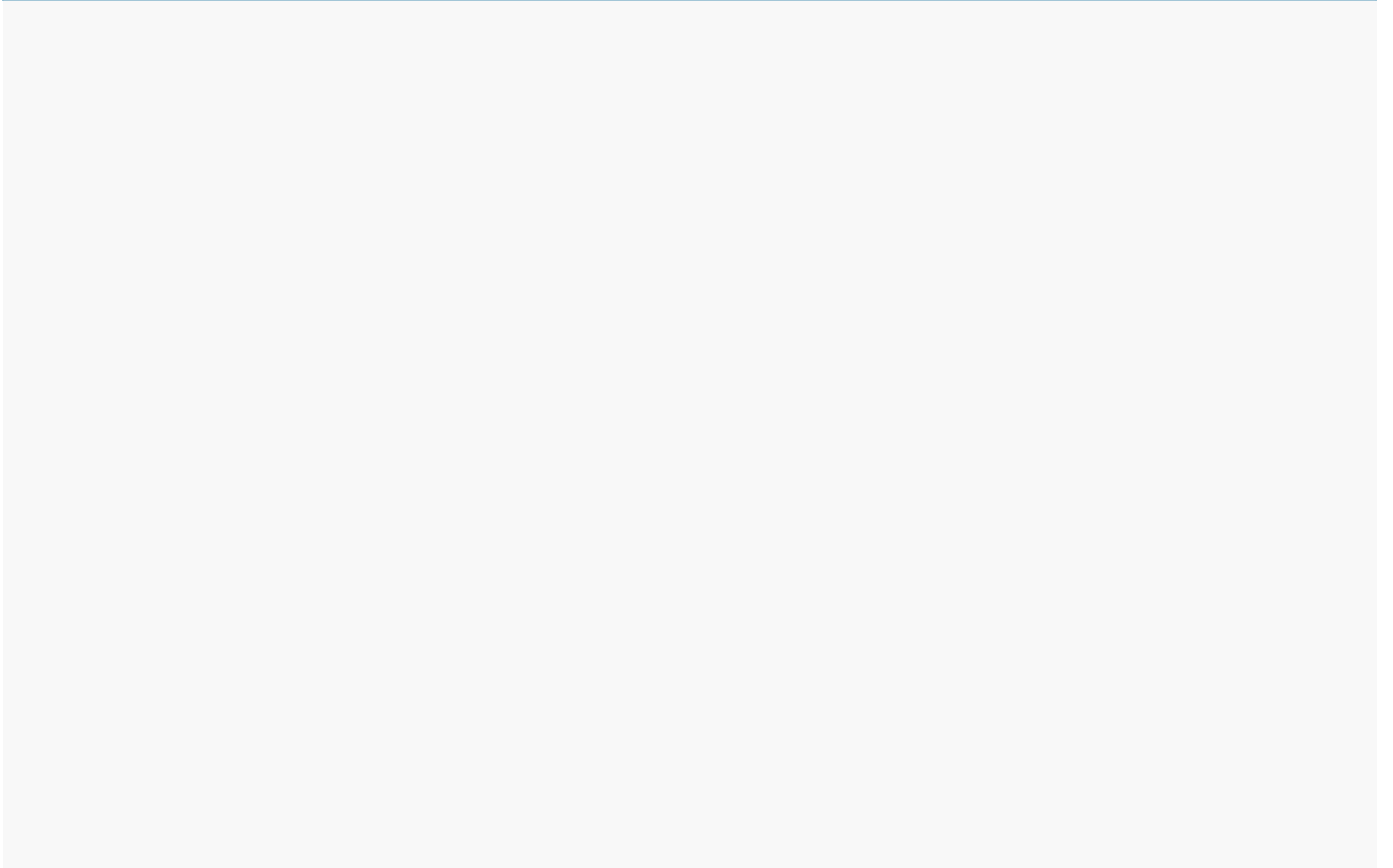
### **GenCell 40 kW system delivered at Connecticut Global Fuel Cell Center, University of Connecticut**



MCFC system being loaded via forklift (inverter cabinet not shown)



Operating in grid-tied mode at CT's Global Fuel Center Center (UCONN)



# Achievements: **AFCo**

►AFCo has targeted a select number of projects to demonstrate fuel flexibility, and other strategic objectives:

|                                     | Size (Class) | Fuel                 | Site                   | Contractual Status | Public Funding       | Partners                                  | Objectives                                    |
|-------------------------------------|--------------|----------------------|------------------------|--------------------|----------------------|-------------------------------------------|-----------------------------------------------|
| <b>First of a Kind</b>              | "Series 2TW" | Natural Gas          | Guadalix-Madrid (E)    | In operation       | EU                   | Iberinco (E), Balke (D) ENEA (I), AMG (I) | Twinstack <sup>®</sup> and MIR demonstration  |
| <b>Technodemo</b>                   | "Series 100" | Natural Gas          | Bosco Marengo (I)      | In operation       | Dept. of Environment | FN (I)                                    | Various test facility functions               |
| <b>Hybrid Cycle</b>                 | "Series 100" | Natural Gas          | Milano (I)             | Signed             | EU                   | CESI (I) Bowmann (UK)                     | Integration with microturbine                 |
| <b>Biomass Application</b>          | "Series 100" | Landfill gas         | Giugliano – Napoli (I) | Under Signature    | Campania Region      |                                           | Landfill gas application                      |
| <b>Naval Application</b>            | "Series 2TW" | Diesel               | Marmara (TK)           | Signed             | WEAO                 | MRC (TK)                                  | Diesel application reformer; Compactness      |
| <b>Biomass Application</b>          | "Series 100" | Biomass gasification | Trisaia (I)            | Fase 1 Concluded   | EU                   | SUT (D), ENEA (I) UNIV. (I,F,UK,A)        | Biomass application Integration with gasifier |
| <b>H<sub>2</sub>/CO<sub>2</sub></b> | "Series 2TW" | Hydrogen             | Milano Bicocca (I)     | Under Negotiation  |                      |                                           | CO <sub>2</sub> separation & management       |
| <b>MC-WAP NAVAL APU</b>             | "Series 2TW" | Diesel               |                        | Signed             | EU                   | Fincantieri                               | ON BOARD OPERATION                            |
| <b>BICEPS</b>                       | "MW-class"   | Digester gas         |                        | Under Signature    | EU                   | MTU                                       | Compactness Scaling up                        |
| <b>FURTHER DEMOS</b>                | "MMW-class"  | various              |                        | -                  | -                    | -                                         | Compactness Scaling up                        |



First of a Kind



Technodemo

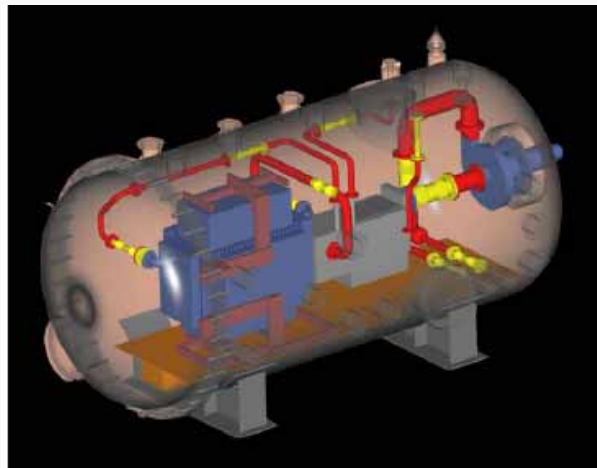
Hybrid Cycle



# Achievements: **AFCo**

## Main Achievements:

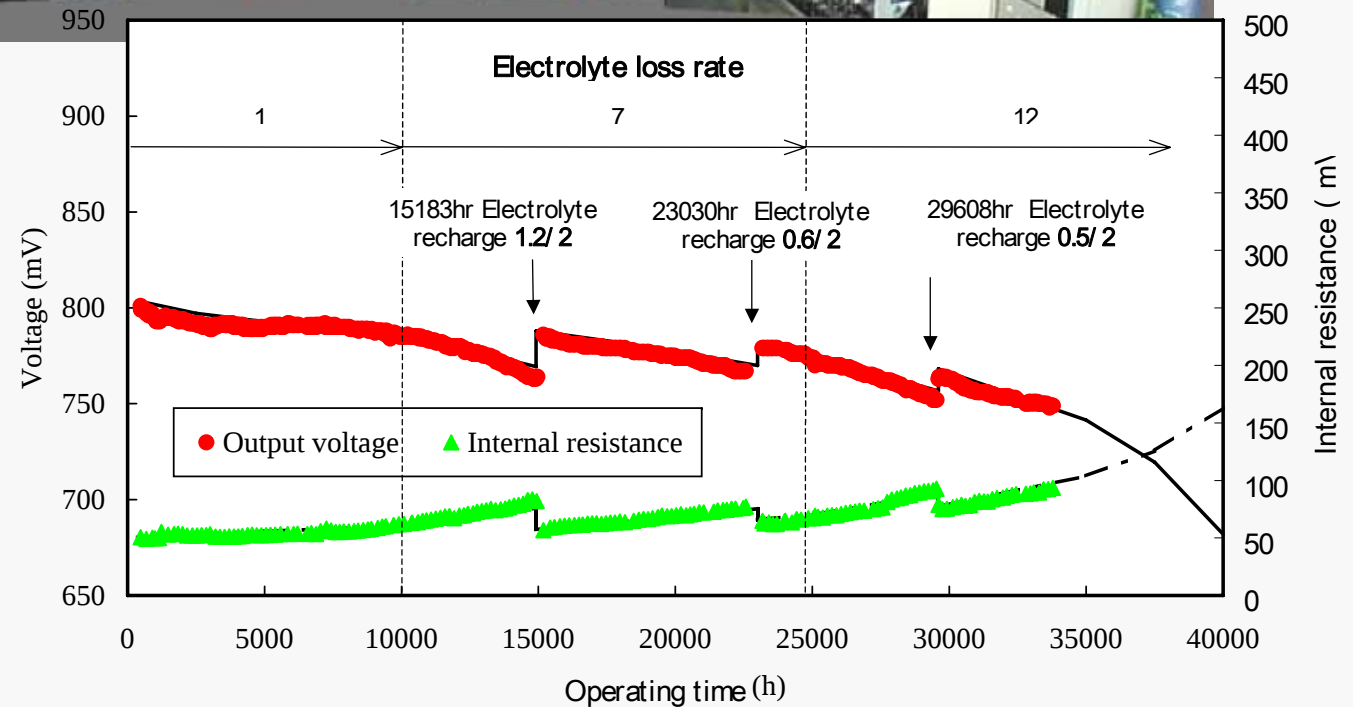
- Demonstrated sub-scale (100 kW) system
- Demonstrated 500 kW systems (TWIN STACK ®)
- Validated Integration of stack-microturbine under static and dynamic conditions
- Validation of control system, power conditioning and grid connection
- 3000 hrs grid connected (technodemo)



# Achievements: IHI



**Endurance  
Tests at  
CRIEPI on  
single cells**



# Achievements: IHI

## MCFC Demonstration Plant in EXPO 2005 Aichi



**Fuel:** NG and Biogas from fermentation systems

**Raw Materials:** Garbage from Restaurants

**Fuel:** NG and Biogas from high temp. gasification systems

**Raw Materials:** Woody chips and plastics

# Achievements: **KEPRI/POSCO**

## ◆ Domestic R&D (KEPRI)



25kW system



100kW stack



100kW stack

## ◆ Demonstration (POSCO)



1<sup>st</sup> DFC300 unit, RIST

- 2<sup>nd</sup> unit: Tanchon waste water treatment site in Seoul
- 3<sup>rd</sup> unit: Chosun University in KwangJu

# The Way Ahead

- Most of the technical problems affecting MCFC have been solved,
  - but some of the solutions applied are still too expensive,
  - therefore we still need R&D programs aiming both to find cheaper processes and/or products and to improve cell, stack, BOP and system performance
- 
- All the players have, more or less, developed products suitable for market entry,
  - but to make products cost effective,
  - there is a strong need to stimulate the market and to reduce costs through R&D (and not just mass production).

# The Way Ahead: **What is needed?**

- International and National policy should make first step promoting fuel cell market throughout:
  - Subsidy Policy (incentives and support to field test demos), strong support to projects aimed at increasing the use of renewable and secondary fuels in MCFC systems (creation of a large niche market that will enable mass production and technological improvements)
  - Support R&D activities aimed to improve the whole system
  - Environmental Policy (i.e. lowering emission limits, making pay those who produce pollution)
- MCFC developers (short – medium term objectives):
  - Standardize their products
  - Meet the needs of the market: cost, operability, reliability
  - Have programs aimed at developing systems (MCFC, gas clean up, reformer/catalysts, gasifier, AD,..), suitable for the utilisation of gases from renewable energy sources
  - Have R&D programs to keep improving their products