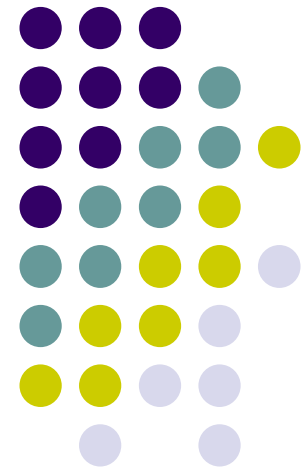
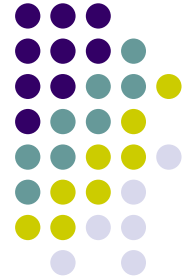


SOFC DEVELOPMENT

by Tokyo Gas, Kyocera, Rinnai and Gastar

- **Tadaaki Ishikawa, Tokyo Gas Co., Ltd.**
Shoji Yamashita, Kyocera Corporation
Tsutomu Sobue, Rinnai Co., Ltd.
Koji Hase, Gastar Co., Ltd.





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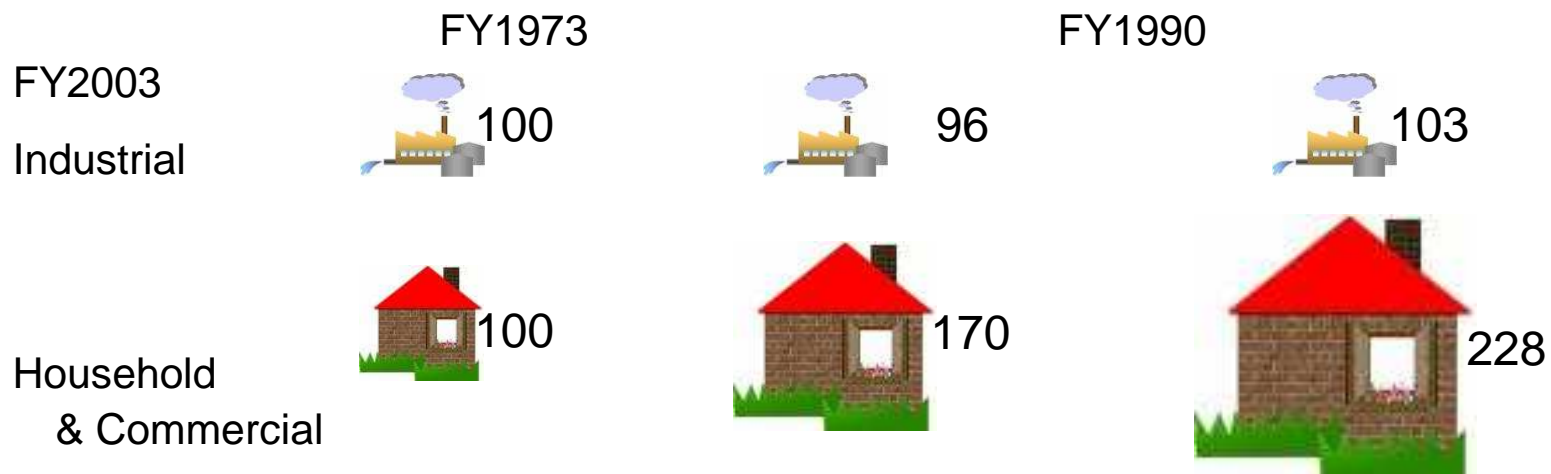
Background of Development

Contribution to the Global Environment



- Contribution to the Global Environment
 - Japan declared Reduction Greenhouse Gas Emissions 6% decrease of 1990 level in 2008 ~ 2012

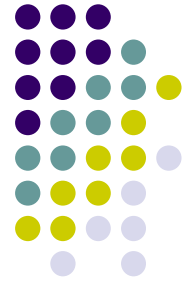
■ Transition of Energy Consumption in JAPAN



→ to promote energy saving,
to develop **on-site co-generation system with higher efficiency**

Background of Development

Changes of Gas Business circumstances in Japan



- Changes of Gas Business circumstances in Japan
 - Electrical grid efficiency improvement
 - Electric driven heat pumps COP improvement
(Turbo Chiller, EHP, CO2 Refrigerant Heat Pump Water Heater)
 - Natural gas advantages for environment might be small.
 - to improve value of natural gas,
to develop **on-site co-generation system with higher efficiency**

We Accelerate Development of SOFC!



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SOFC Development approach of TG

Characteristic comparison of various fuel cells



	Polymer Electrolyte Fuel Cell (PEFC)	Phosphoric Acid Fuel Cell (PAFC)	Molten Carbonate Fuel Cell (MCFC)	Solid Oxide Fuel Cell (SOFC)
Electrolyte	Proton exchange membrane	Phosphoric acid	Molten alkaline carbonate	Oxide Ceramics (Zirconia)
Operating Temp.	Room Temp. to 100°C	200°C	750°C	up to 1,000°C
Charge Carrier	H ⁺	H ⁺	CO ₃ ²⁻	O ²⁻
Fuel	H ₂	H ₂	H ₂ , CO	H ₂ , CO
Efficiency ($\frac{HH}{V}$)	~ 35%	~ 36%	~ 50% + α	~ 50% + α
Applications	Automobile, Residential CGS	CGS	CGS, Power Station	CGS, Power Station 1kW ~ MW
Turbine Combined System	Not available	Not available	Available	Available
Reformer for Methane Fuel	Necessary	Necessary	NOT necessary	NOT necessary
Specifications	Easy start-up, Practical use stage	Practical use stage	High efficiency, Large scale	High efficiency, Low cost manufacturing

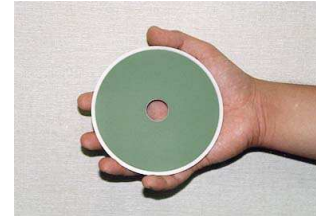
SOFC Development approach of TG



Transition of SOFC Development

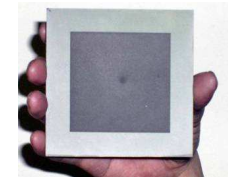
FY1989 ~ FY 2000 (TG)

- Planar-type SOFC operable at high temperature (1,000°C)
 - Electrolyte-self-supporting type cell
 - Generated over 1kWe by internal reforming of methane.



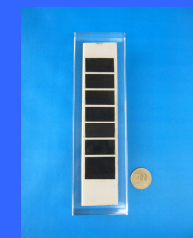
FY1998 ~ FY2005 (TG)

- Development of Planar-type SOFC operable at intermediate temperature (750°C)
 - anode-supported cell
 - partly supported by NEDO (from FY2001 to FY2004)



FY2004 ~ present (TG, Kyocera, Rinnai, and Gastar)

- 「Flat-tubular segmented-in-series type SOFC at intermediate temperature (740°C)





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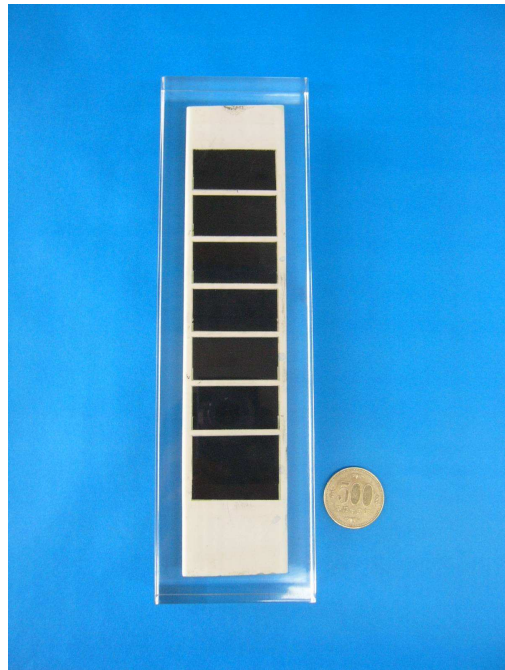
SOFC Development by 4-Companies

Formation of Development



Cells-Stack, Bundle

TG/Kyocera



6 june 2006

System

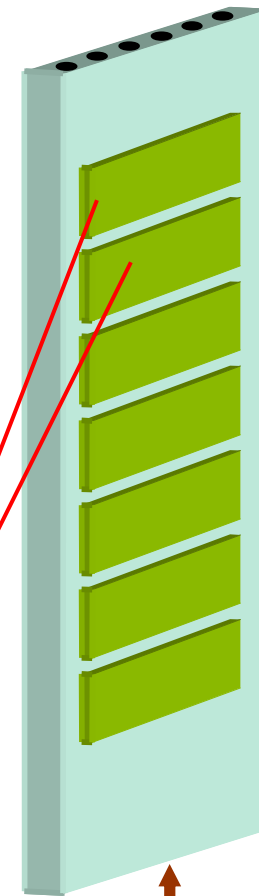
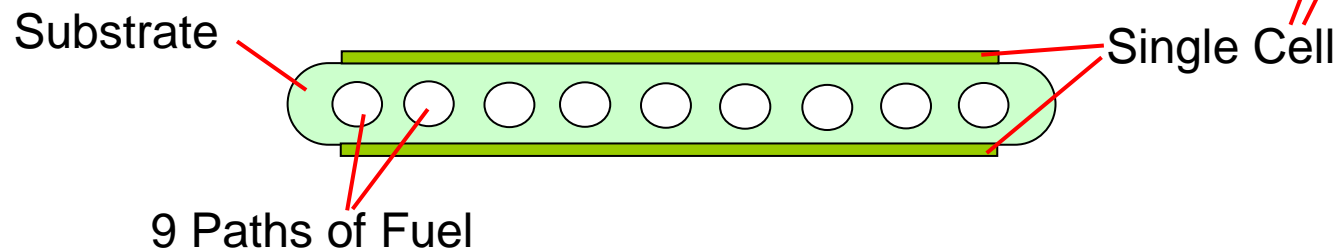
**TG/Rinnai/Gastar/
Kyocera**



SOFC Development by 4-Companies

Features of Flat Tubular Segmented-in-Series Type Cells-Stack of SOFC

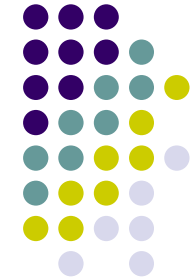
- **High Voltage/Low Current**
- **Compact**
- **Lower Manufacturing Cost**
- **Modifications of Inter-connect**
→ **intermediate temperature operation**



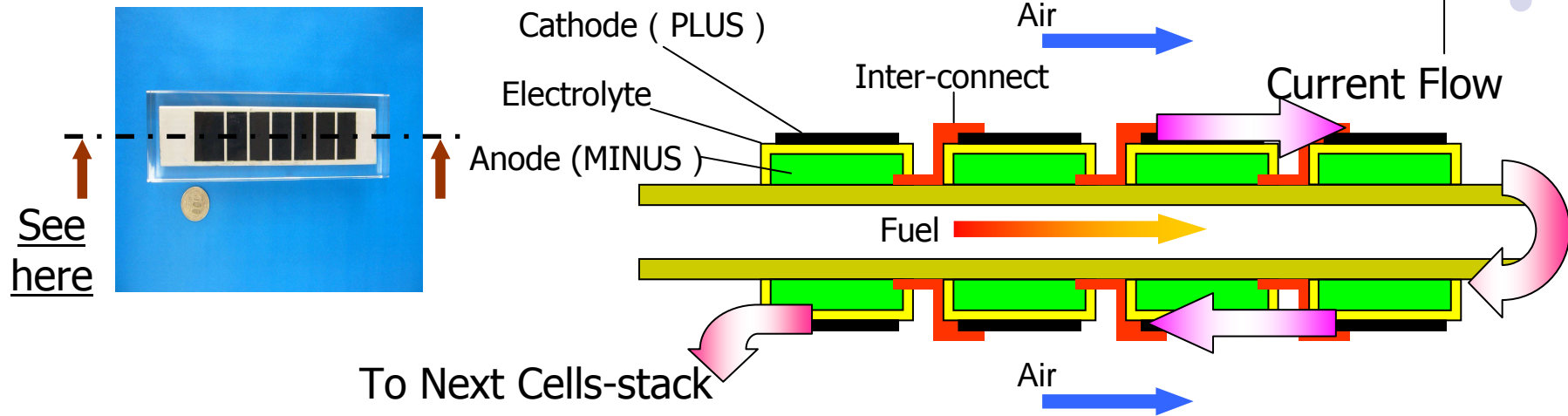
See here

SOFC Development by 4-Companies

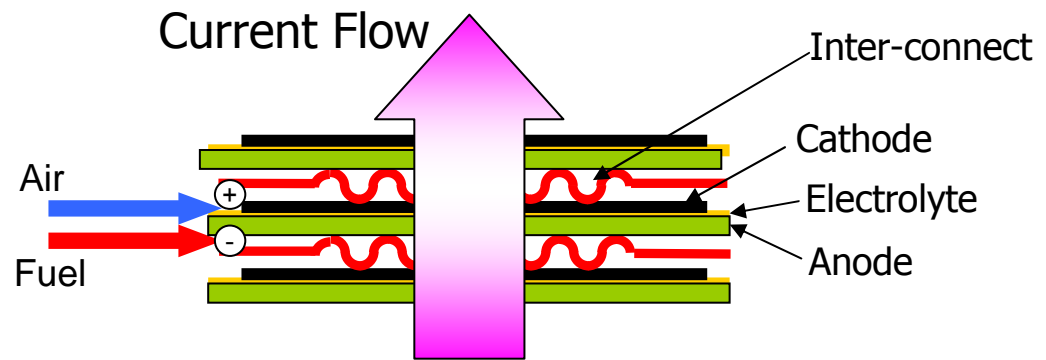
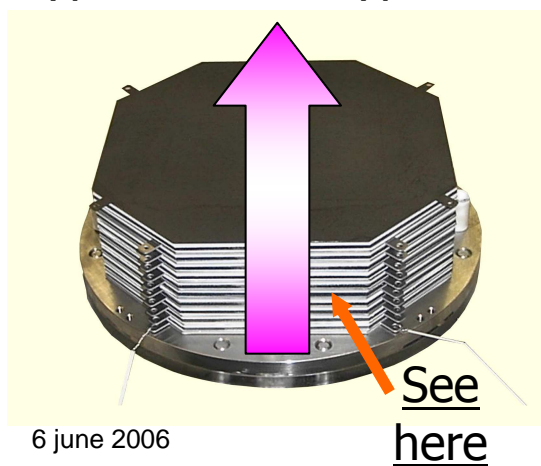
Current Flow on/through a Cells-stack



Flat Tubular Cells-stack

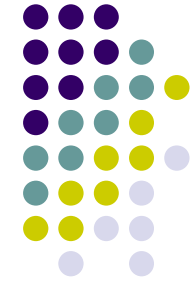


Cf. Typical Planar Type Cells-stack



SOFC Development by 4-Companies

Integration of SOFC system

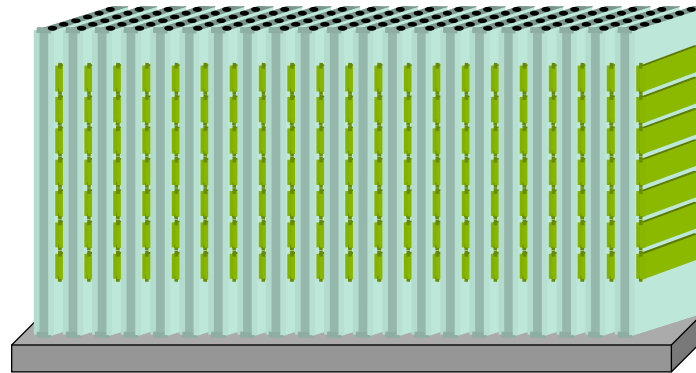


**Cells-Stack (10We)
(14 Cells on Both Sides)**

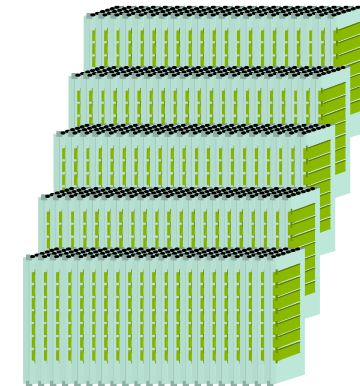


Single Cell

**a Bundle (210We)
(21 Cells-Stacks)**

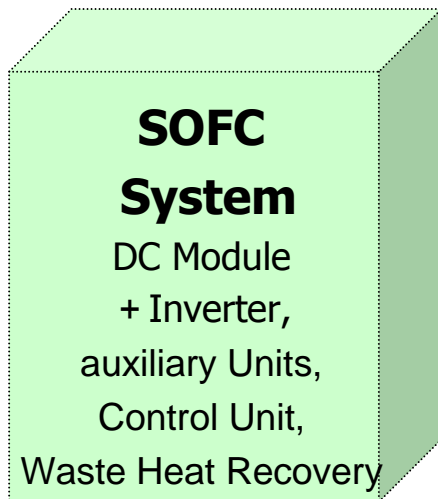


Manifold

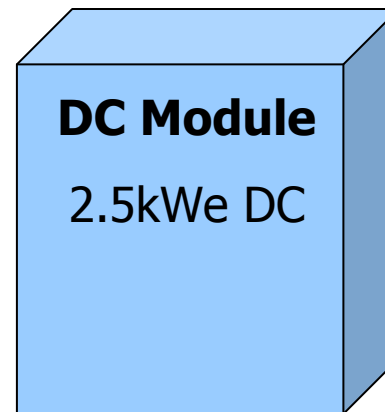


12 Bundles

Now Developing



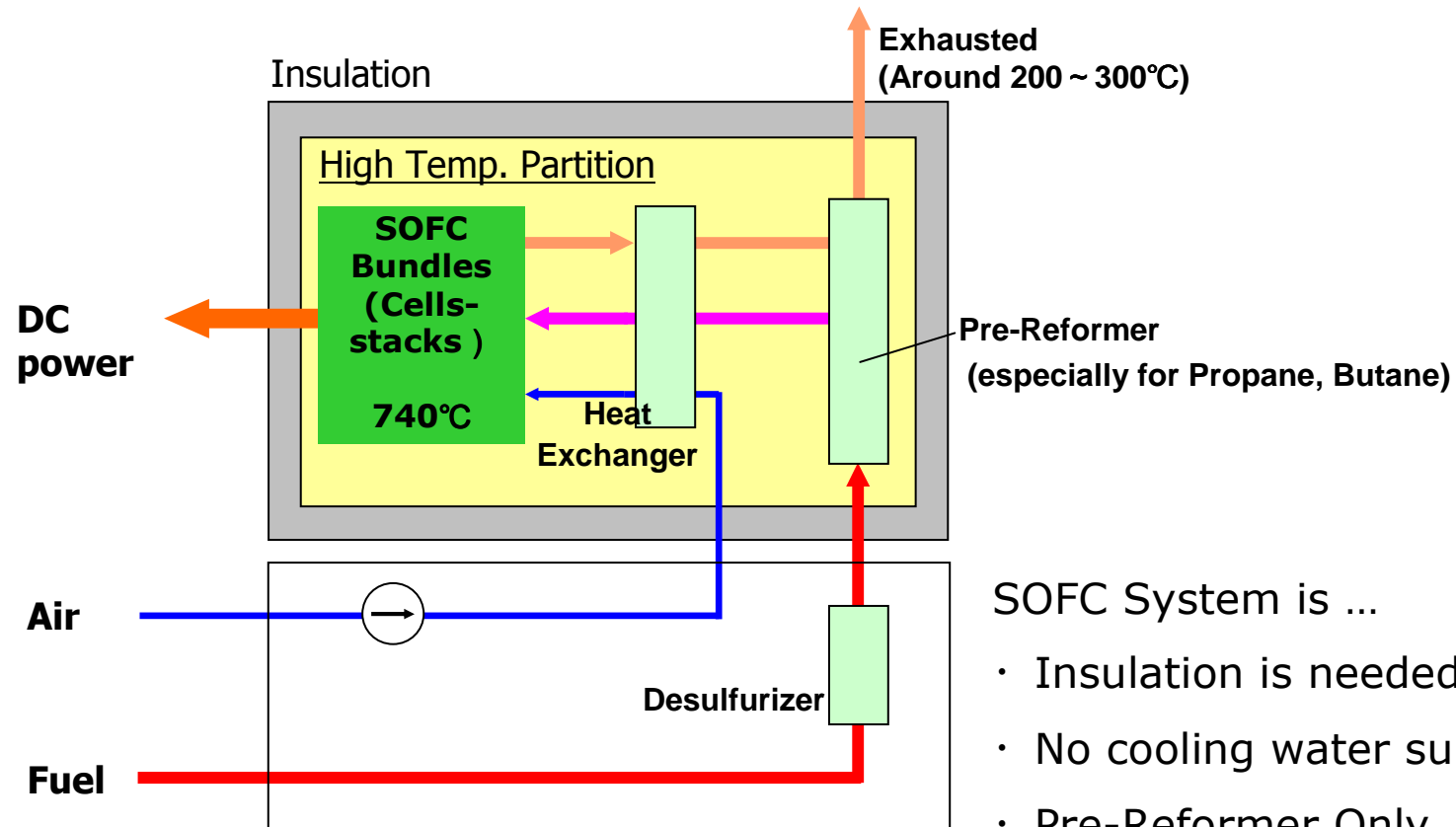
Present Stage



6 june 2006

SOFC Development by 4-Companies

DC Module Diagram

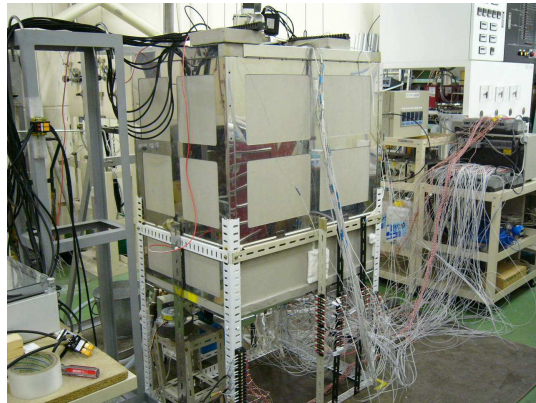


SOFC System is ...

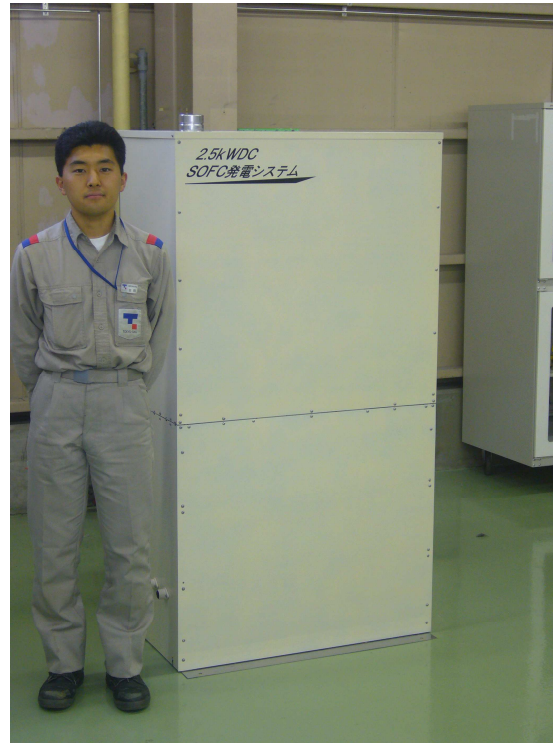
- Insulation is needed
- No cooling water subsystem
- Pre-Reformer Only
- Exhausted reaches to 200 ~ 300°C

SOFC Development by 4-Companies

Outlook of SOFC DC module & DC system

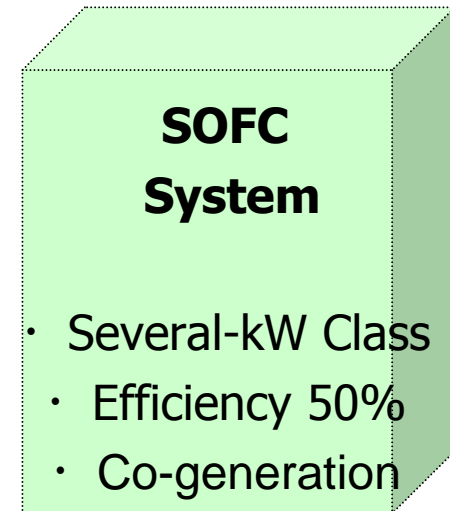


2.5kWe DC Module



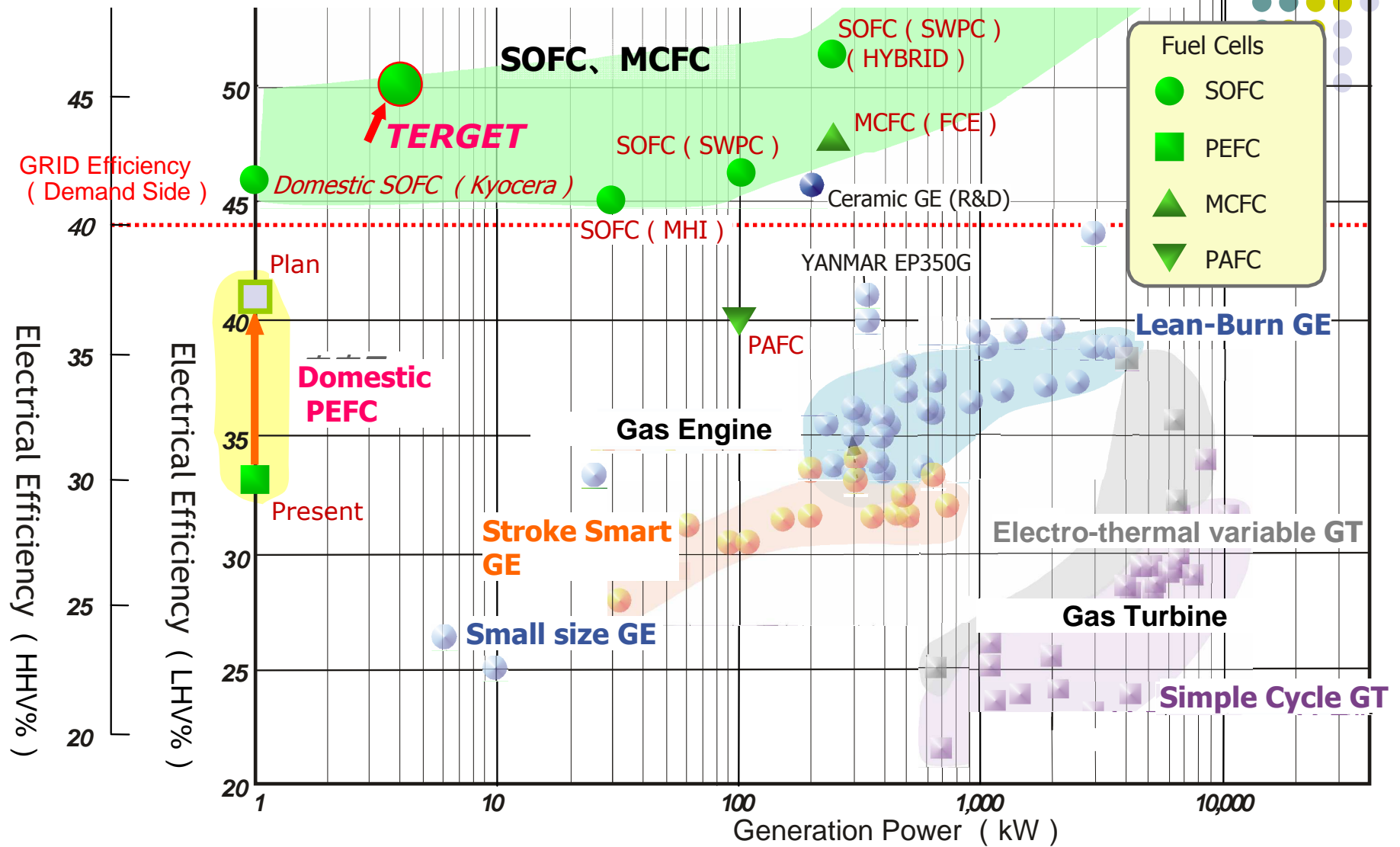
2.5kWe DC system

Now Developing



SOFC Development by 4-Companies

Map of various distributed power system



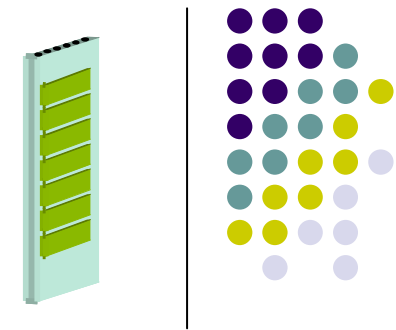


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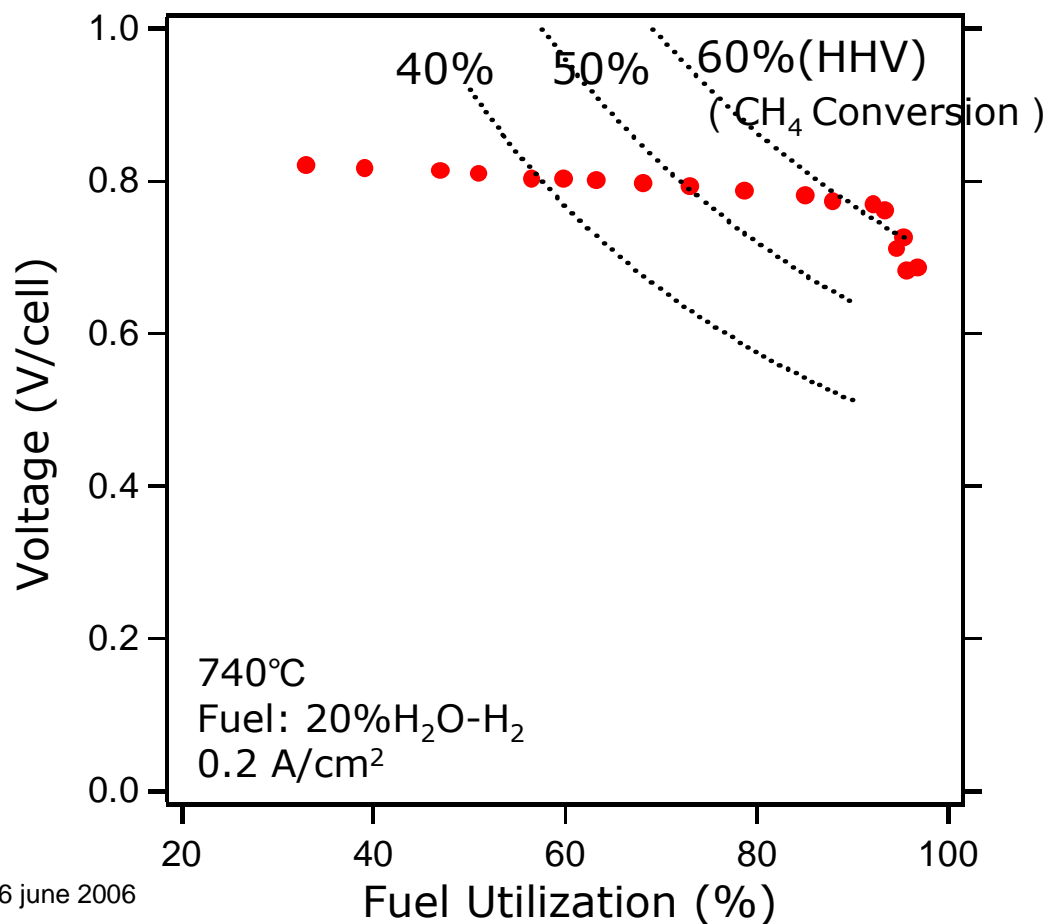
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Progress of Development

Performance of a Cells-stack (1)



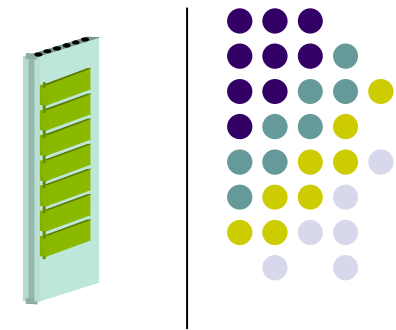
- Fuel Utilization Ratio Dependence



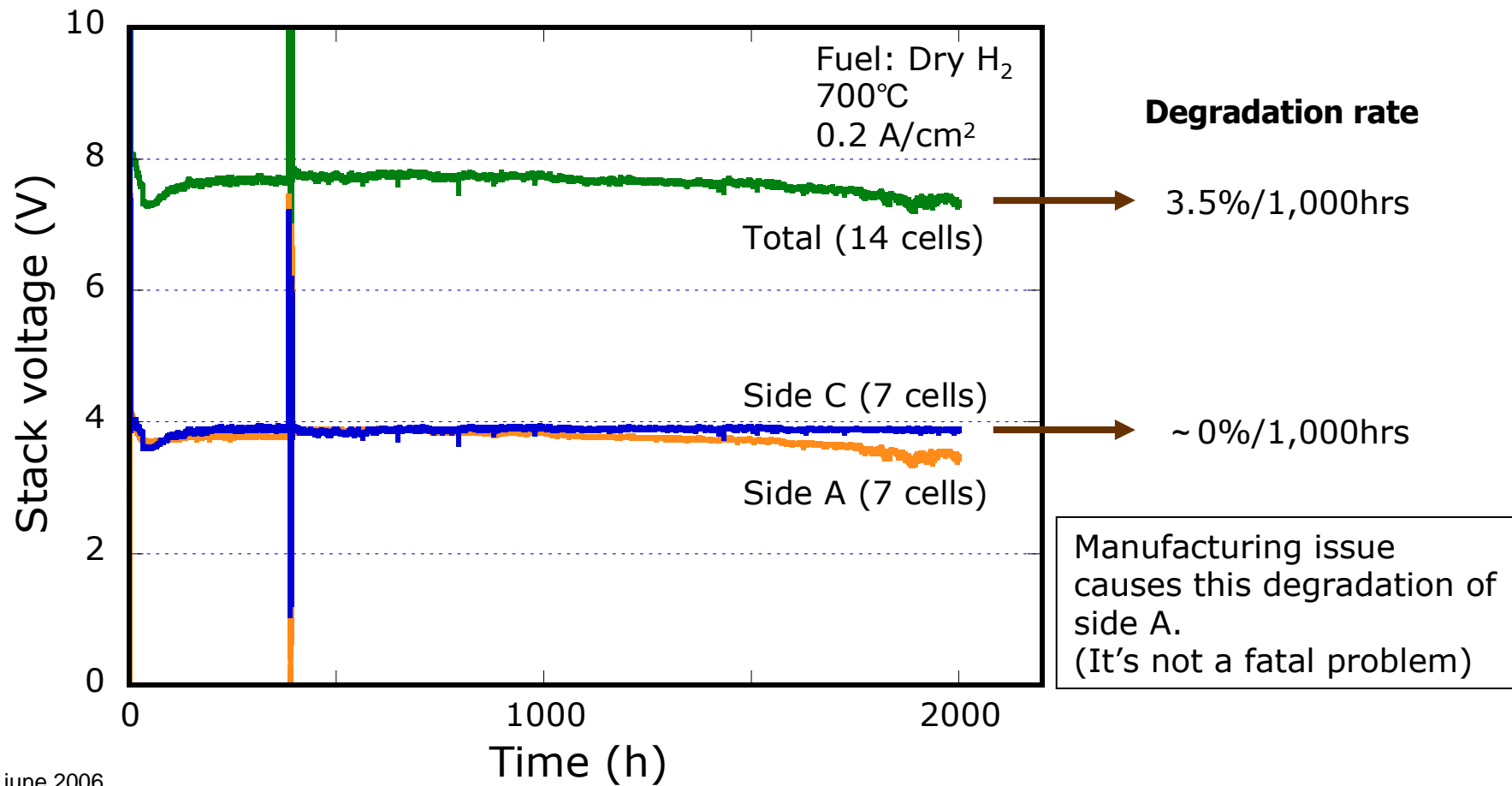
*CH ₄ Conversion	
Uf(%)	η(%) (LHV)
70	53.6
80	60.5
85	64.0

Progress of Development

Performance of a Cells-stack(3)

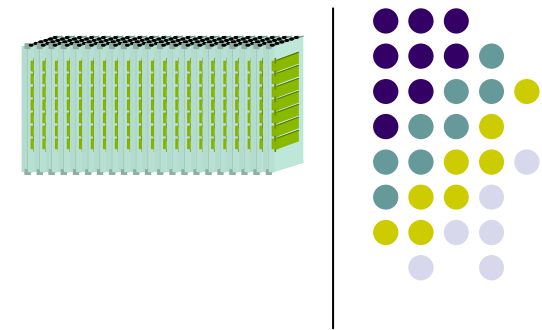


- Durability of a Cells-Stack

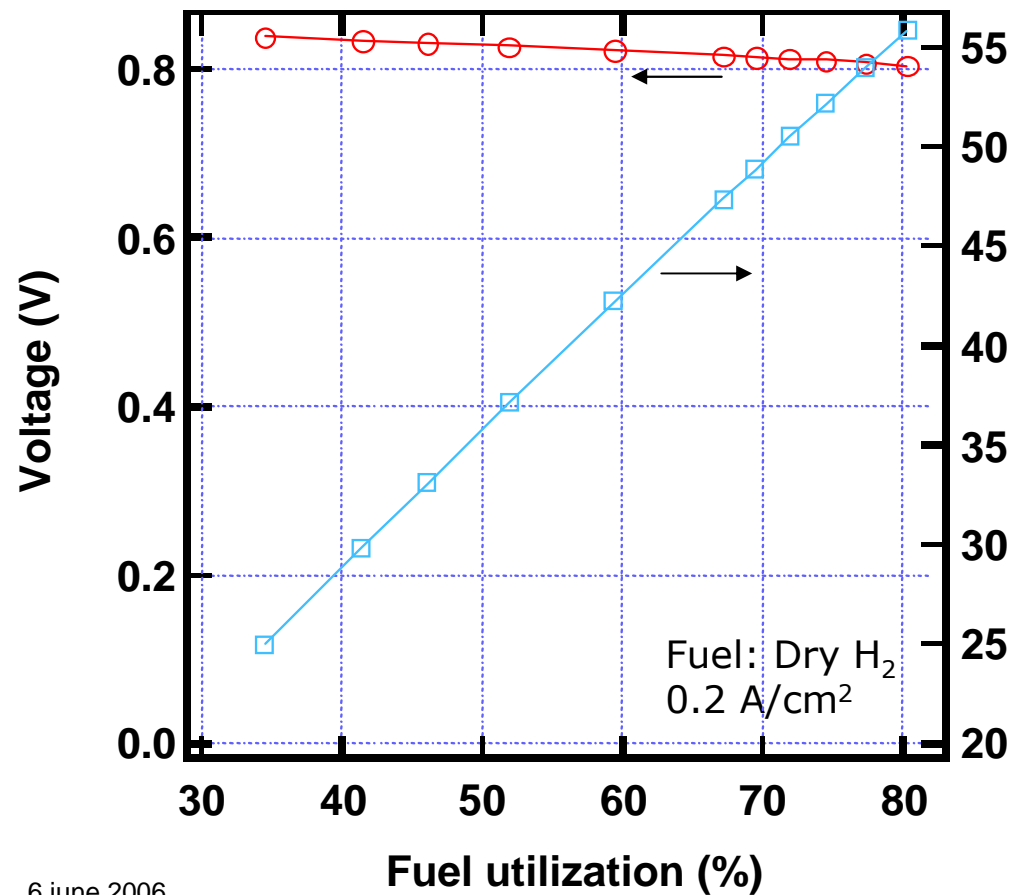


Progress of Development

Performance of a bundle



- Fuel Utilization Ratio Dependence

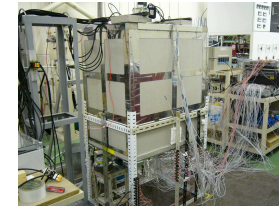


*CH ₄ Conversion	
Uf (%)	η (%) [LHV]
80	61.9

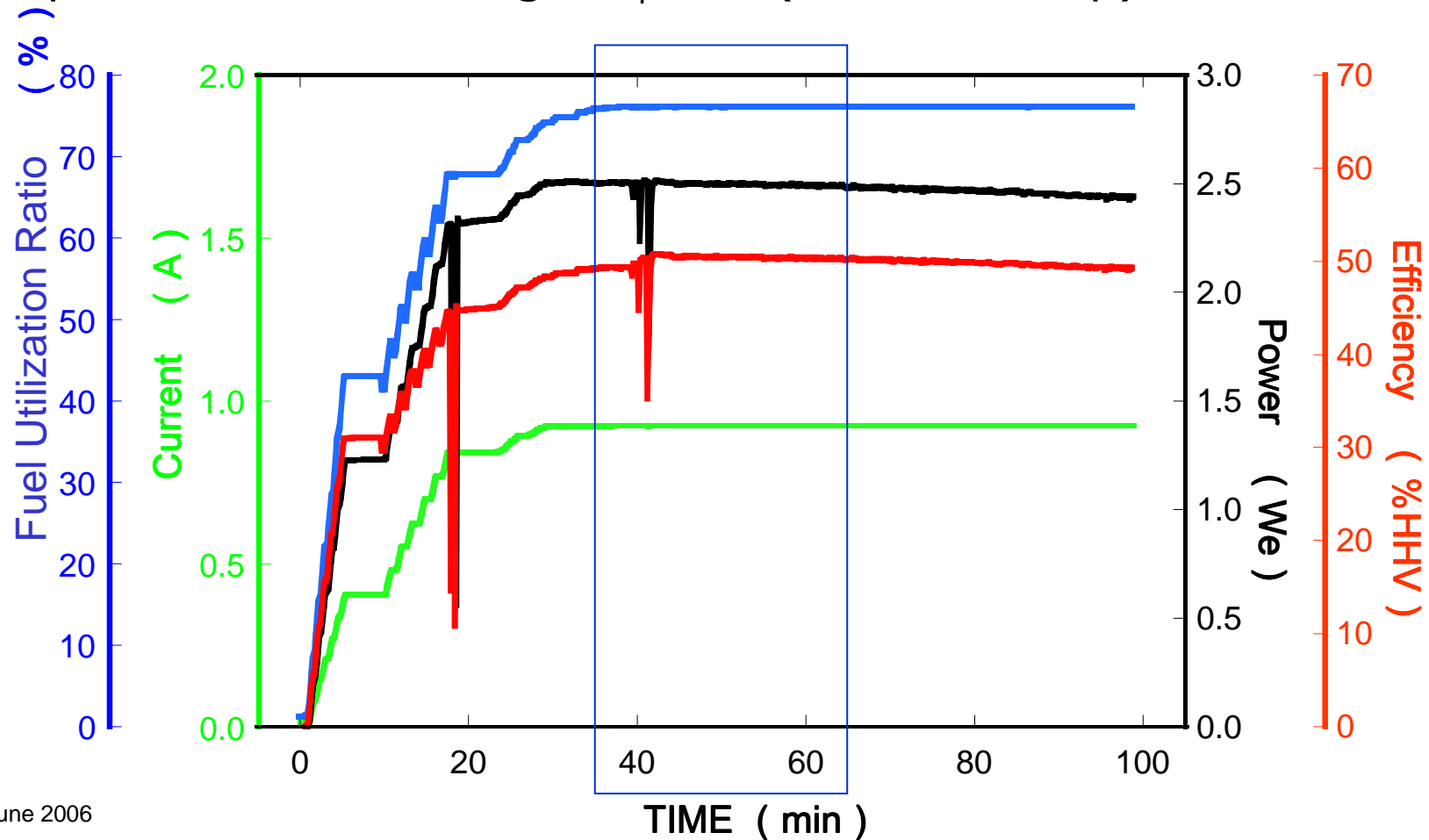
*CH₄ Conversion

Progress of Development

Performance of a DC Module (1)



- Operation Result using CH₄ Fuel (from Start-up)



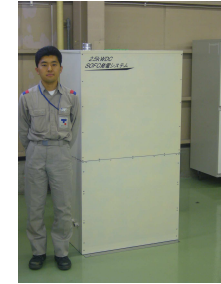


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Conclusions

Conclusions(1)

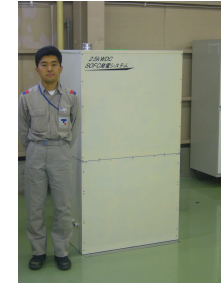


Summary of Development

- We have concentrated on a 「Flat Tubular Segmented-in-Series Type SOFC」 since FY2003.
 - Confirmed High Performance of cells-stacks and bundles
- We have developed DC module equipped with the cells-stacks.
 - Achieved Electrical Efficiency 56.1% LHV-DC at 2.5kWe

Conclusions

Conclusions(2)



Plan of Development

- Cells-stacks
 - Durability Confirmation

- System
 - CHP(CGS) System Development
(DC module + Inverter, Auxiliary units,
Control unit & Waste heat recovery
unit etc.)
 - Reliability Improvement
 - Cost Reduction
 - Target Electrical efficiency 50%LHVAC(NET)
 - Several kW Class

→ We aim at practical use of SOFC in several years.

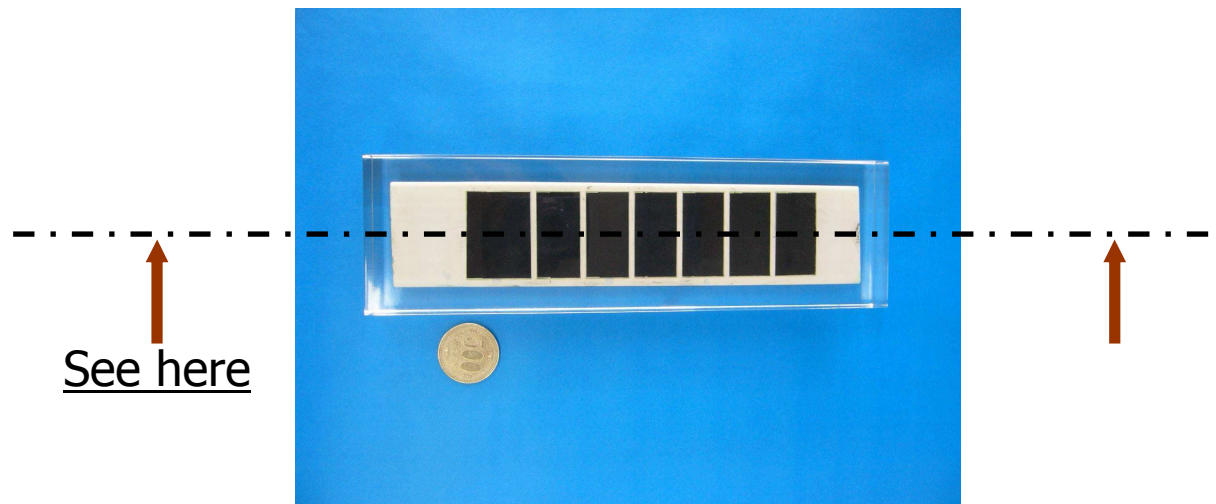
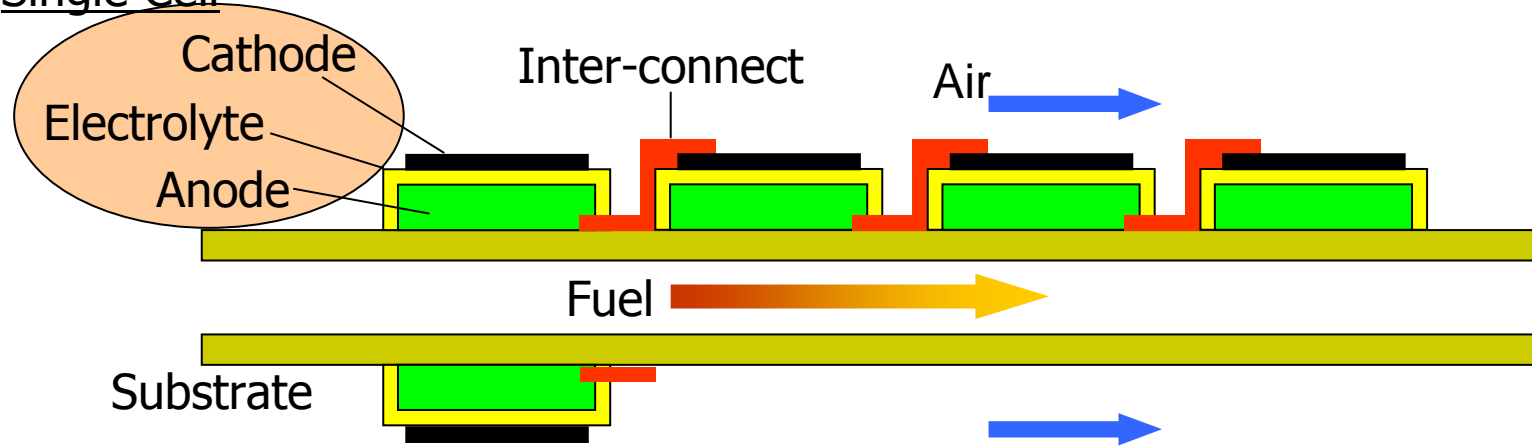
6 june 2006

SOFC Development by 4-Companies

Configuration of Flat Tubular Segmented-in-Series Type Cells-Stack of SOFC

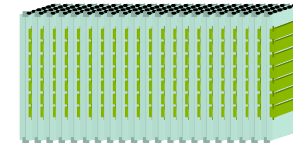


Single Cell



Progress of Development

Performance of a bundle (1)



- Output Power of Each Cells-stack

