Intermediate Temperature Solid Oxide Fuel Cell (IT-SOFC) Research and Development Activities at MSRI

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Outline

- MSRI history and background
- MSRI SOFC technology development
- Summary

ABOUT

MATERIALS & SYSTEMS RESEARCH, INC.

MSRI

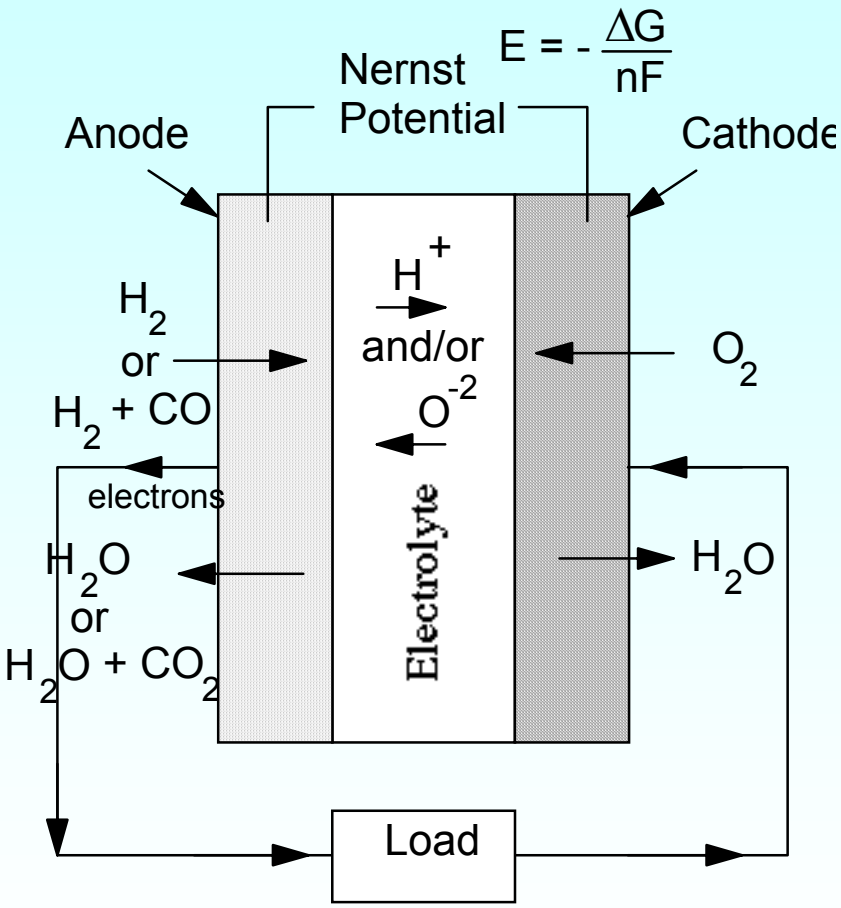
MSRI is a privately held corporation. MSRI's facilities include 10,000 sq. ft. of high quality laboratory space on a 1.8 acre lot in the industrial sector of Salt Lake City, less than 10 minutes from the SLC international airport.

- **Organization: President (1), Vice President (1), Consultant (1), Research Scientist (4), Research Engineer (6), Research Technician (5), Administrative (1)**

- **Facilities: High temperature furnaces; complete powder processing facility; laminating presses; isostatic press; tape casters; electrochemical testing facility; impedance spectroscopy; glove box; electroplating, complete fuel cell fabrication & testing facilities (single cell and stack), PCs and workstation.**

- **Technologies: Solid oxide fuel cell – anode-supported planar / tubular, sodium beta" alumina, sensors, ceramic materials, high temperature heating elements**

What Is A Fuel Cell



SOFC Technology for Distributed Power Important Features

- High Efficiency
- Potentially Low Cost
- Environmentally Friendly
- Fuel Flexibility
- No Moving Parts
- Potentially High Reliability
- Modularity

MSRI Founding Opportunities – Fuel Cell

Finished Projects

DARPA

- ✓ A solid oxide fuel cell (SOFC)-based portable power source – STTR Phase I & II.

DOE

- ✓ Intermediate temperature (650 °C), high power density solid oxide fuel cells;
- ✓ A metallic interconnect for intermediate temperature, planar, solid oxide fuel cells – SBIR Phase I & II;
- ✓ LSGM based composite cathodes for anode supported, intermediate temperature (600-800 °C) solid oxide fuel cells – SBIR Phase I & II (II is on-going);
- ✓ High power density solid oxide fuel cells (SOFC) with rapid start-up capabilities for auxiliary power units.

NIST – ATP

- ✓ Reduced-temperature, electrode-supported, planar (RTESP) solid oxide fuel cell (SOFC) system for premium power applications;
- ✓ High power density, reduced temperature, anode-supported, planar solid oxide fuel cells.

NSF

- ✓ Low temperature solid oxide fuel cells with electrolytes made by electrochemical vapor deposition (EVD);
- ✓ Advanced, polycrystalline t ' - zirconia ceramics for high temperature applications – SBIR Phase I & II;
- ✓ Novel, highly permeable and selective ceramic membranes for the separation of oxygen from air.

GTI

- ✓ RTESP SOFC stack design, fabrication and testing.

VPS

- ✓ SOFC stack development for a thermally-integrated power system (TIPS).

MSRI Founding Opportunities – Fuel Cell

Current Projects

CEC

- Design, construction, and operation of a power module for high efficiency, low-cost, multi-fueled 10-100 kW solid oxide fuel cells

DARPA

- Development of 75 W SOFC generator set

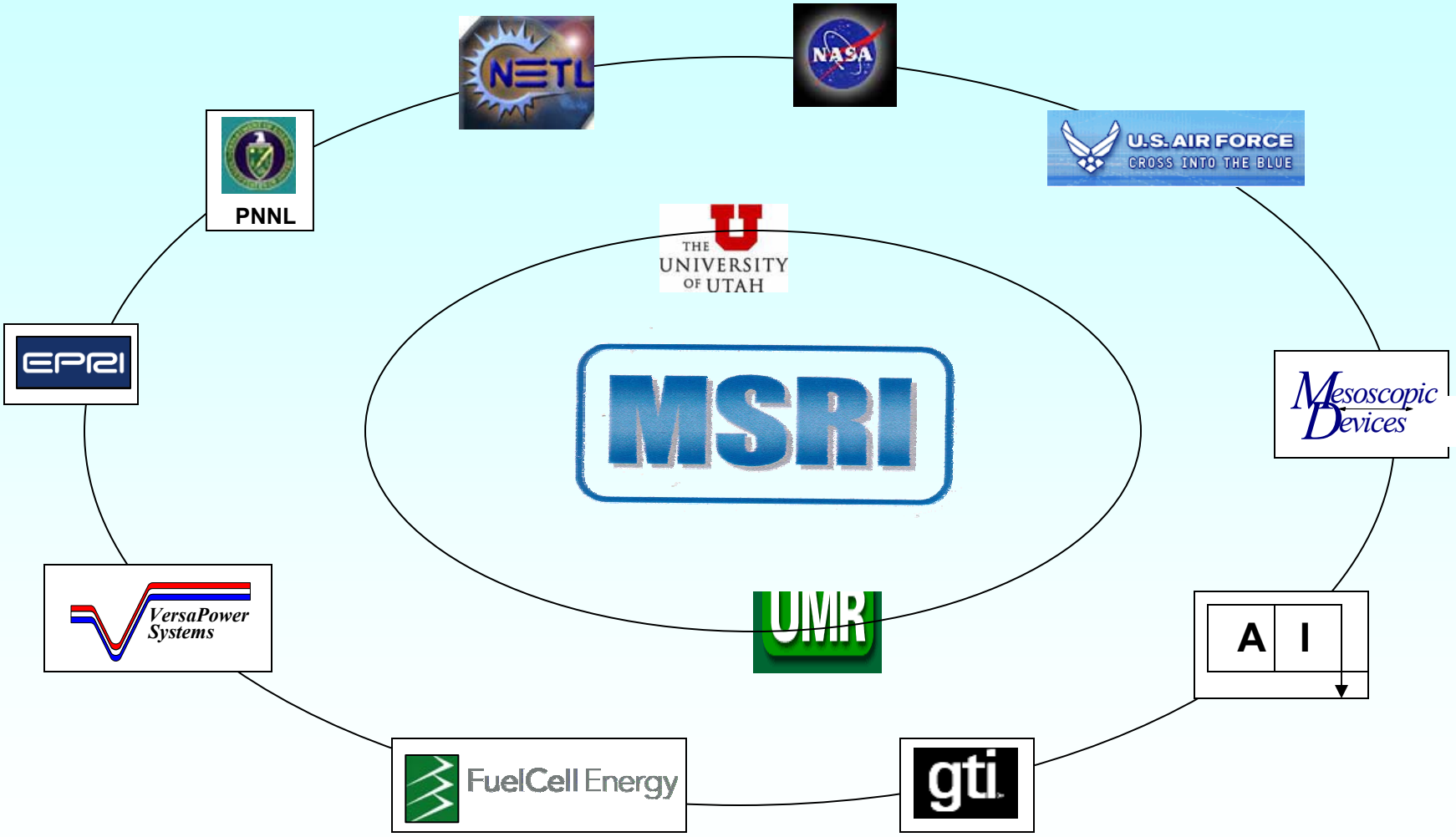
DOE

- LSGM based composite cathodes for anode supported, intermediate temperature (600 - 800 ^{o}C) solid oxide fuel cells – SBIR Phase II;
- A Reversible Planar Solid Oxide Fuel-Fed Electrolysis Cell and Solid Oxide Fuel Cell for Hydrogen and Electricity Production Operation on Natural Gas/Biomass Fuels

SECA

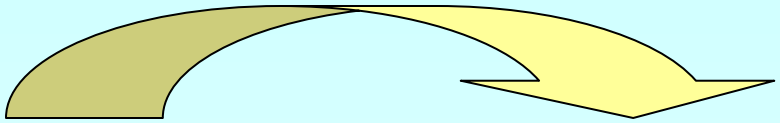
- Thermally integrated high power density SOFC generator

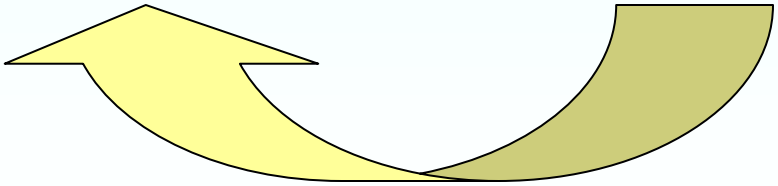
MSRI Partnership



Technology Implementations and Interactions

Cell technology & Advance materials:
Lab-level button cell



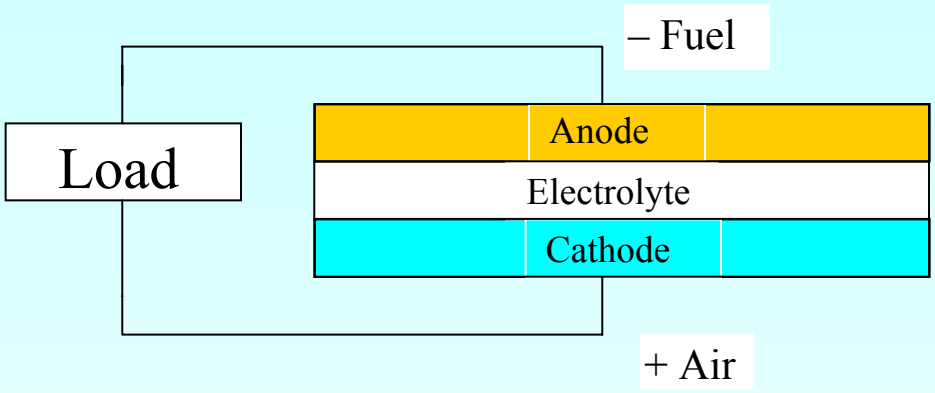


High power density stack &
Advanced materials:
Lab-level button cell;
Bench-scale stack;
Seal; System integration

MSRI

SOFC TECHNOLOGY DEVELOPMENT

SOFC Materials



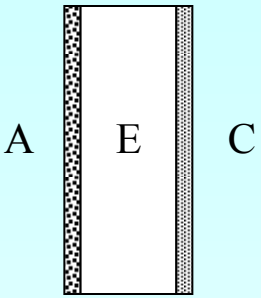
Materials for the SOFCs

Electrolyte:	8YSZ (8% Y_2O_3- 92% ZrO_2)
Anode:	Ni + YSZ
Cathode:	LSM (Sr-doped $LaMnO_3$) + YSZ

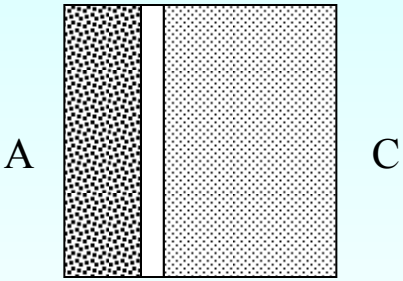
Temperature: >650°C (As high as 1000°C)

Fuel: Natural gas (methane), propane, gasifiable liquid hydrocarbons
Processed (reformed – internally or Externally)

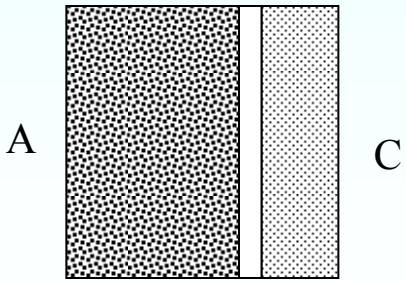
Types of SOFC



Electrolyte-Supported: (1) **High Ohmic Contribution**
(2) **Low Cathode Concentration Polarization**
(3) **Low Anode Concentration Polarization**



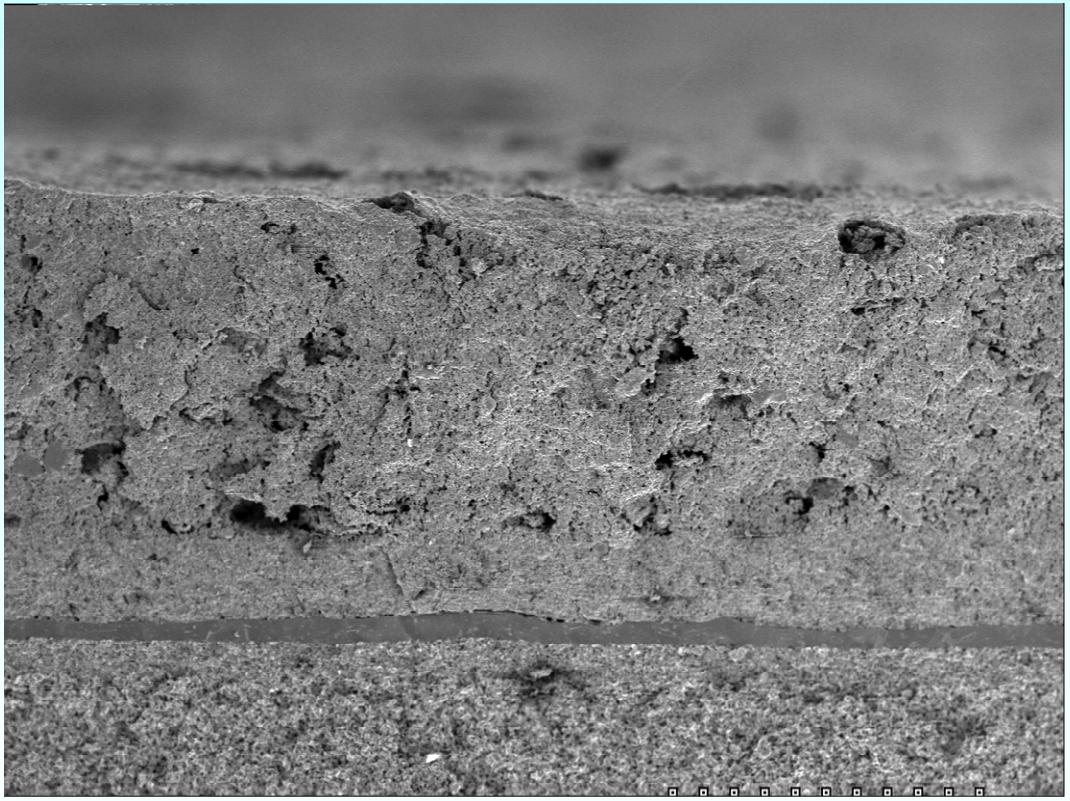
Cathode-Supported: (1) **Low Ohmic Contribution**
(2) **High Cathode Concentration Polarization**
(3) **Low Anode Concentration Polarization**



Anode-Supported: (1) **Low Ohmic Contribution**
(2) **Moderate Anode Concentration Polarization**
(3) **Low Cathode Concentration Polarization**

Best Choice from Polarization Standpoint: Anode-Supported

MSRI State-of-the-art SOFC

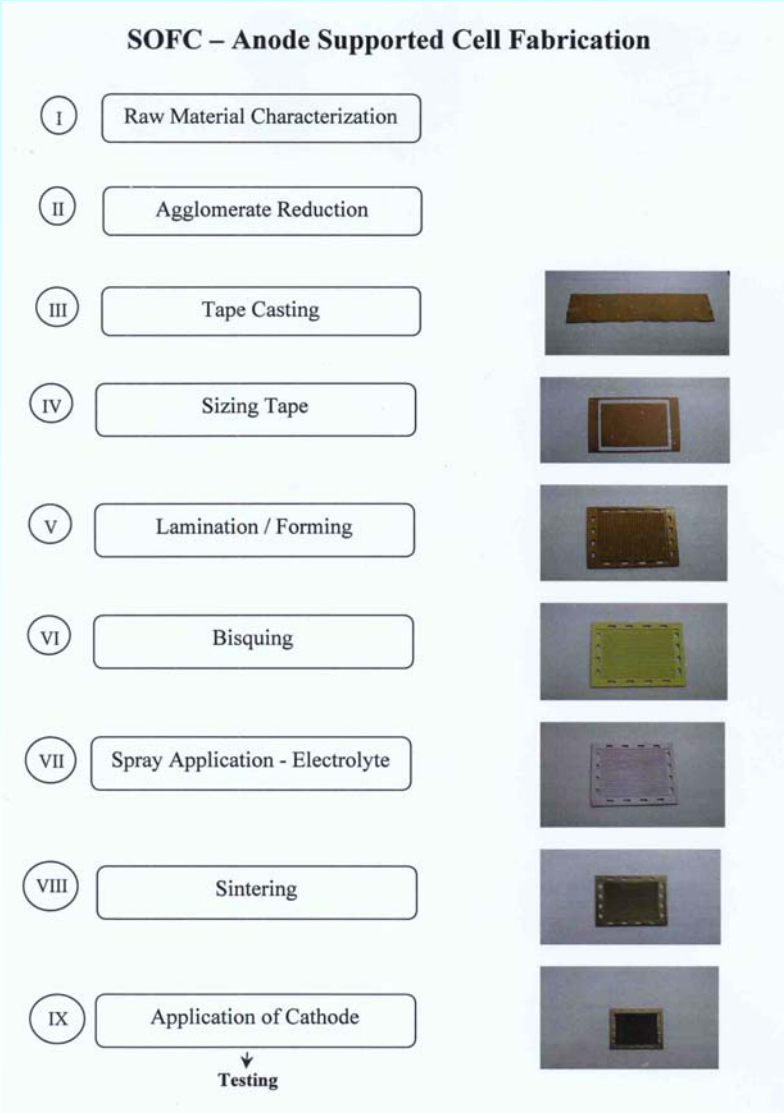


- *Anode* – nickel-zirconia cermet, -- 0.5~0.8 mm thick
- *Electrolyte* – yttria-stabilized zirconia (YSZ), -- 5~10 μm thick
- *Cathode* – conducting ceramic/composite, -- 50~90 μm thick

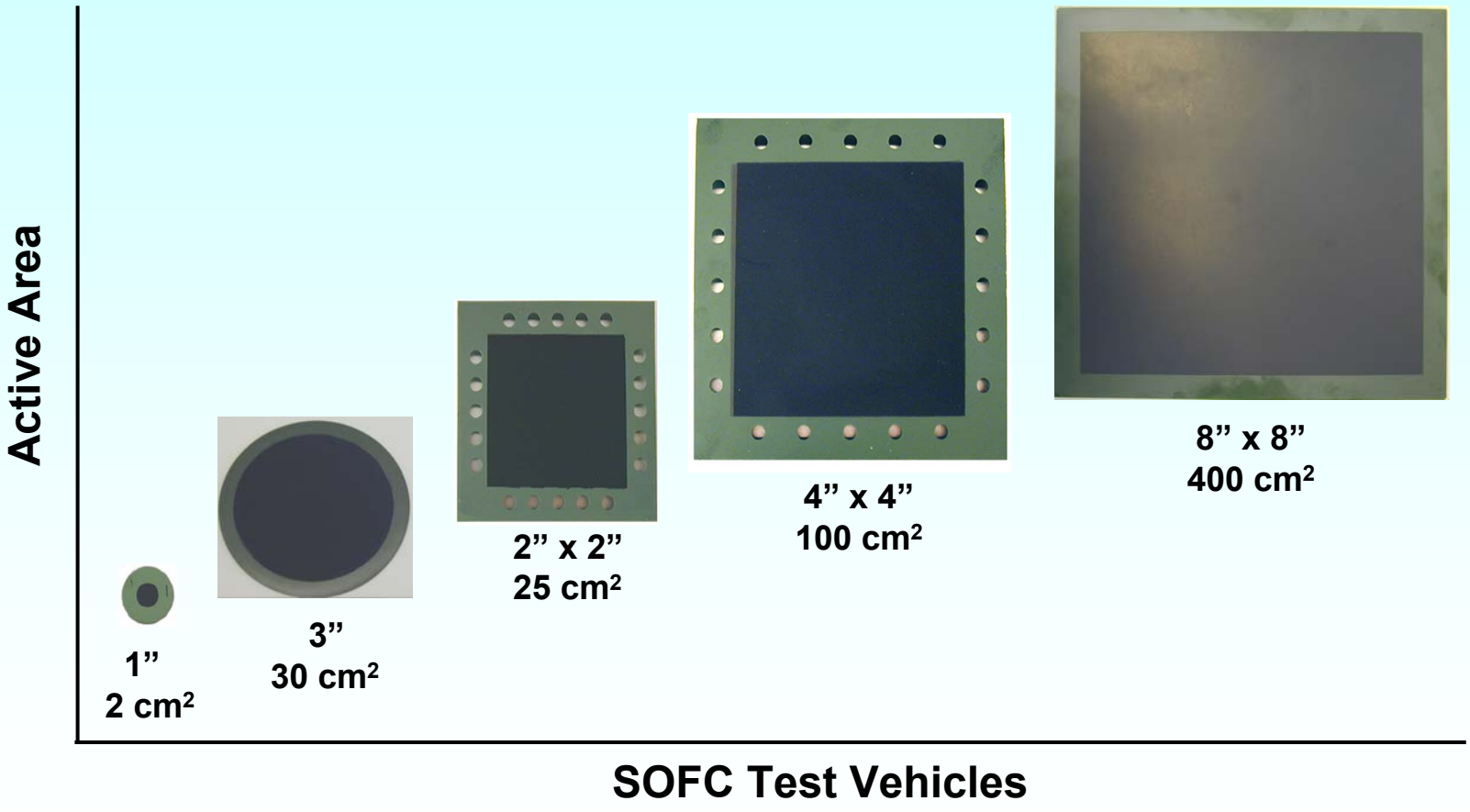
MSRI SOFC Cell Fabrication Process Flow

Stack Fabrication

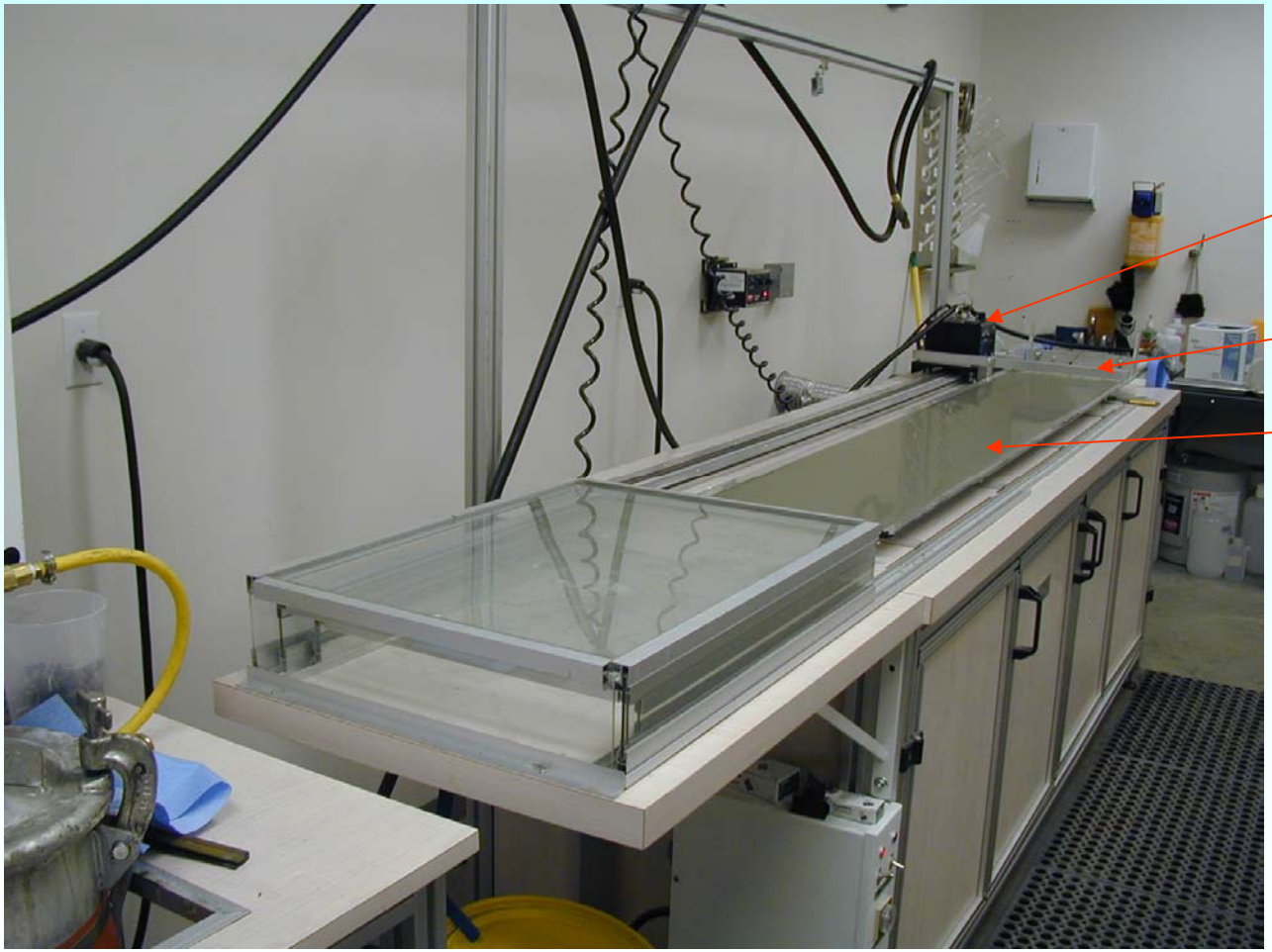
- Raw materials and formulation;
- Tape casting;
- Tape sizing and lamination;
- Bisquing;
- Anode interlayer and electrolyte deposition;
- Sintering;
- Cathode application.



Cell Scale-up



Anode Tape Casting



Tape casting capable of producing 12 inch wide and 6 feet long green tape

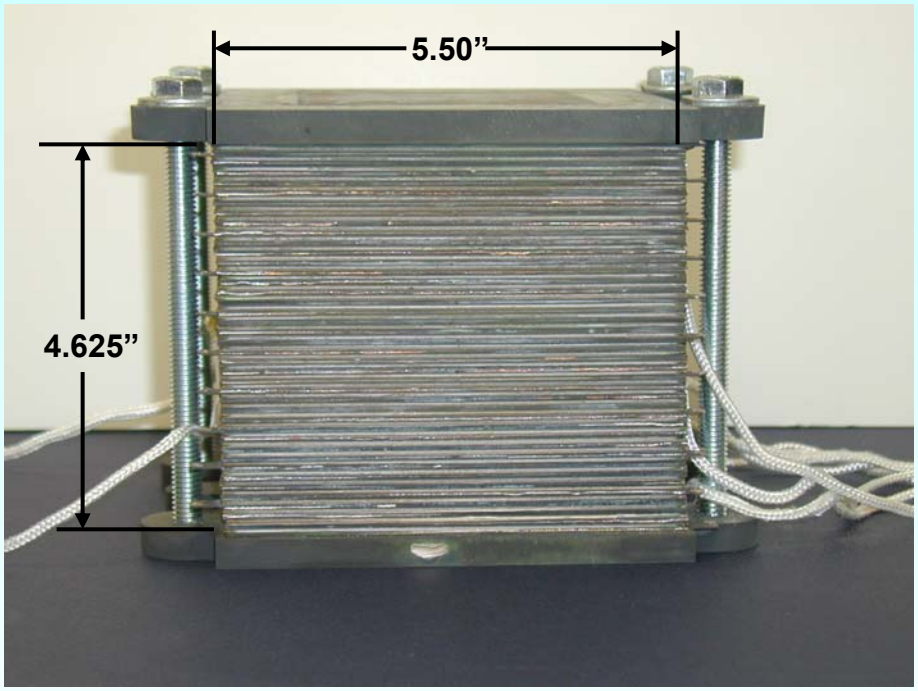
Lamination and Sintering

Laminating Press

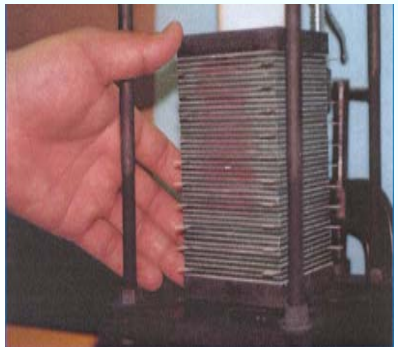
Sintering furnace

MSRI State-of-the-art Stacks Built

A



C



B

A. MSRI state-of-the-art stack architecture;
B. 40-cell 2” x 2” stack, active area 32 cm^2 per cell;
C. 40-cell 4” x 4” stack, active area 92 cm^2 per cell.

Stack Testing Facility

Interior view of the stack testing stand

MSRI Stack Testing Area

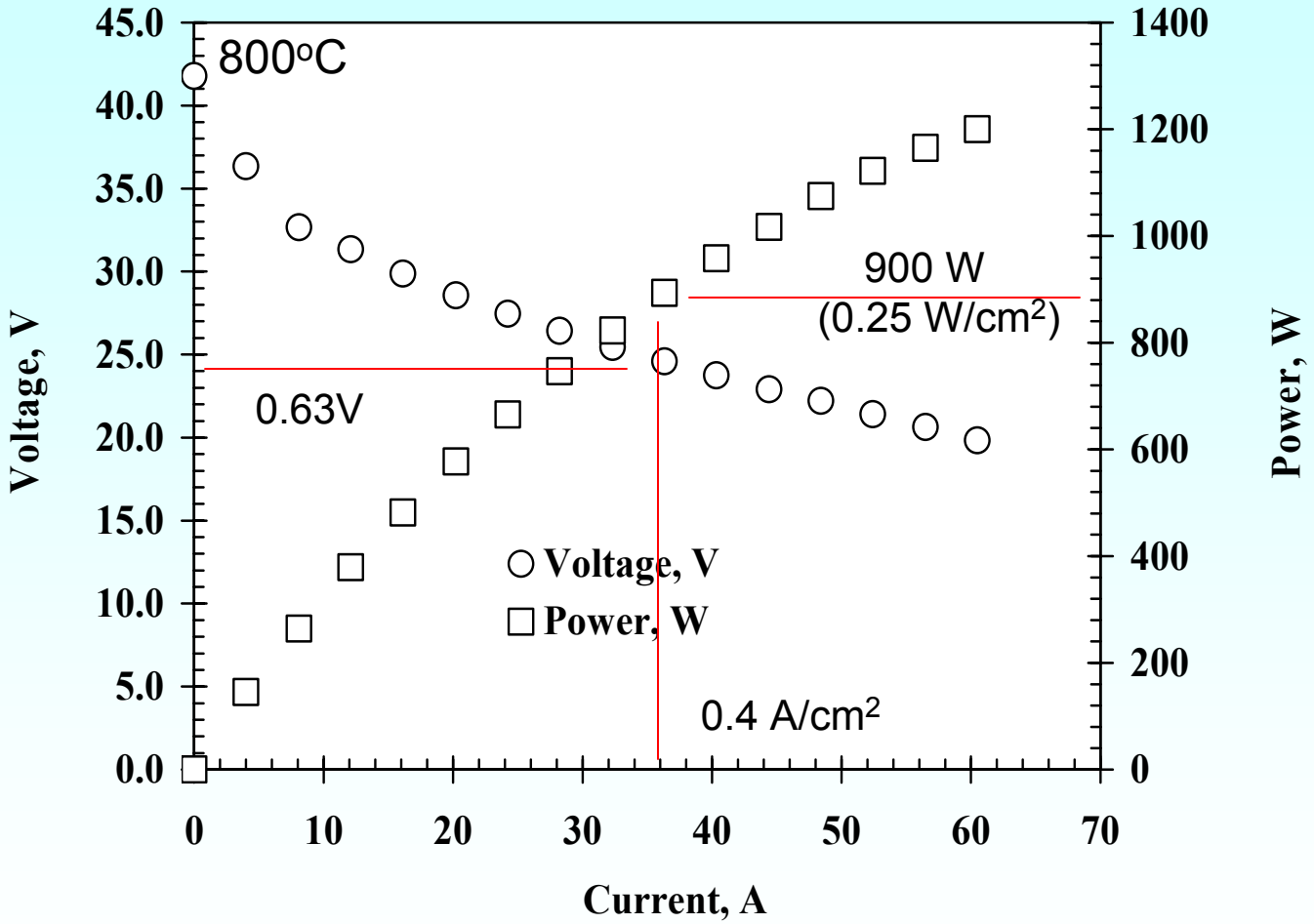
- 5 testing stations;
- Capable of 40+ cell stack;
- Automation testing;
- Temperature up to 1000°C;
- Self protection in case of power failure;
- Gases inlet / outlet different flow patterns;
- Gas chromatograph (GC) composition analysis;
- Stack IR evaluation.

SOFC System – Portable Power Source

First generation of portable power source

Second-generation power module

Performance of a 40-cell Stack
4” x 4” Cells with 90 cm^2 Active Area

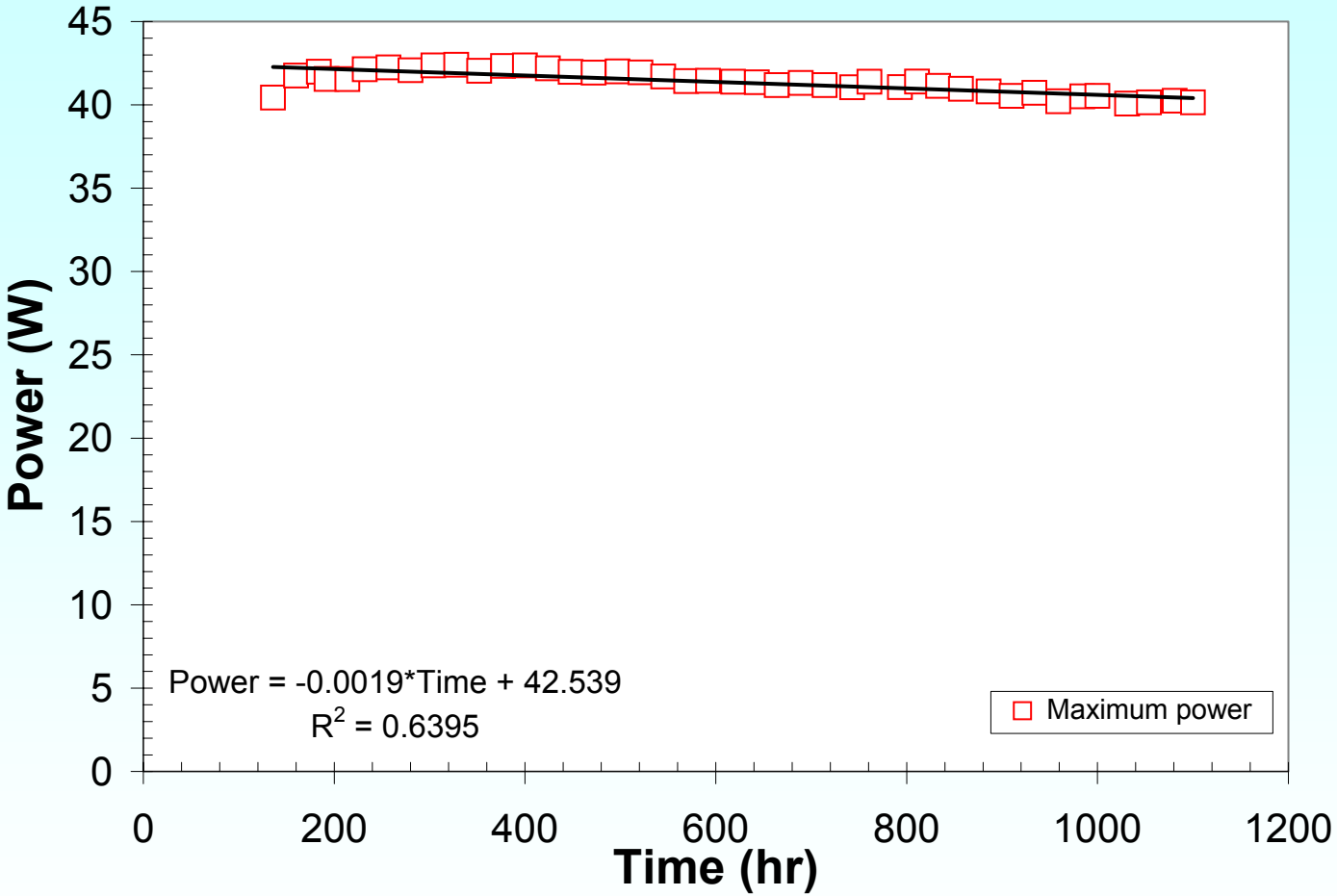


(-) H_2, Ni-YSZ/YSZ/LSM, Air (+)

H_2/air: Uf/Ua = 40/40, MSRI standard cell

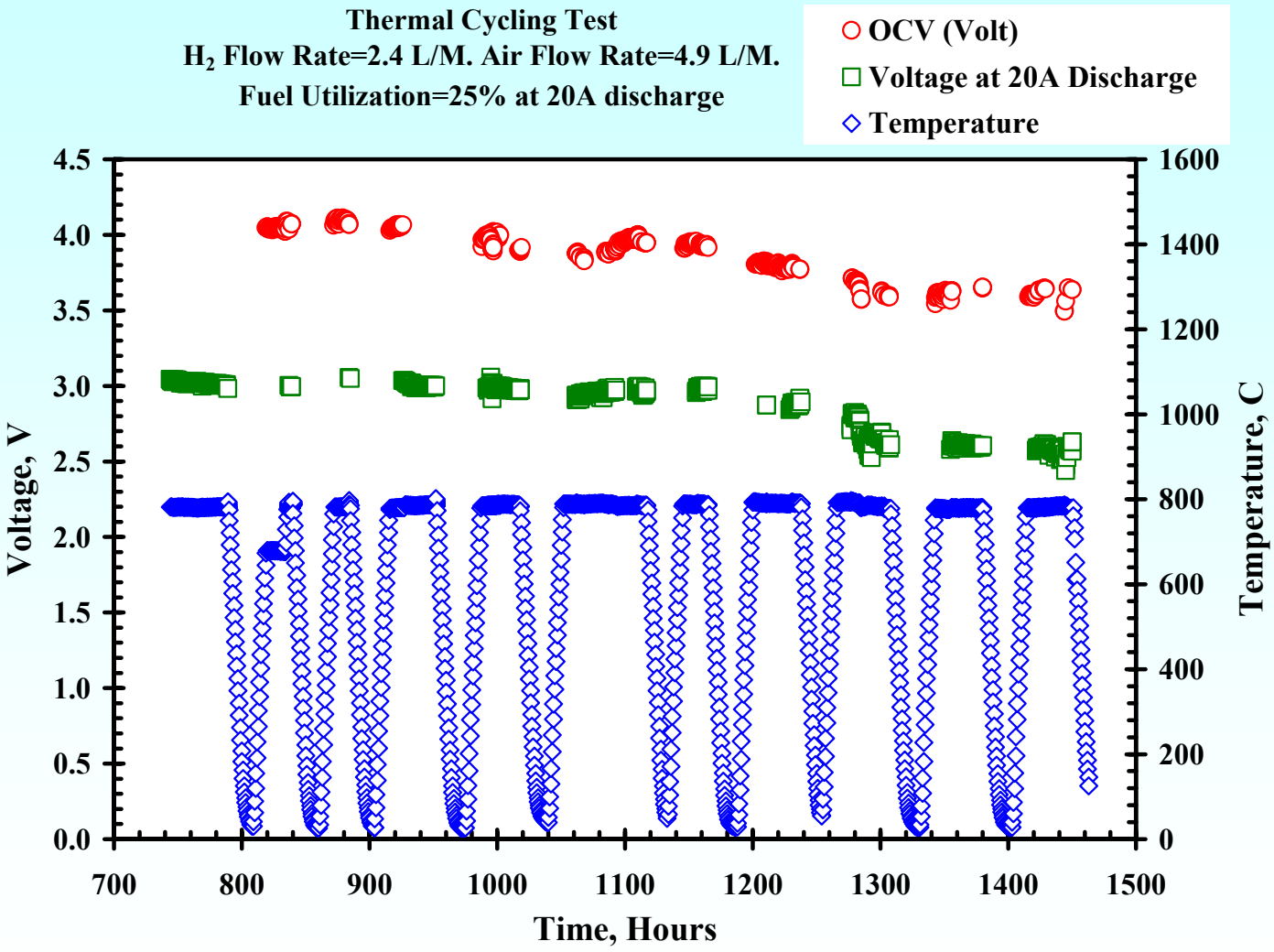
> 1 kW stack

Stack Degradation Investigation



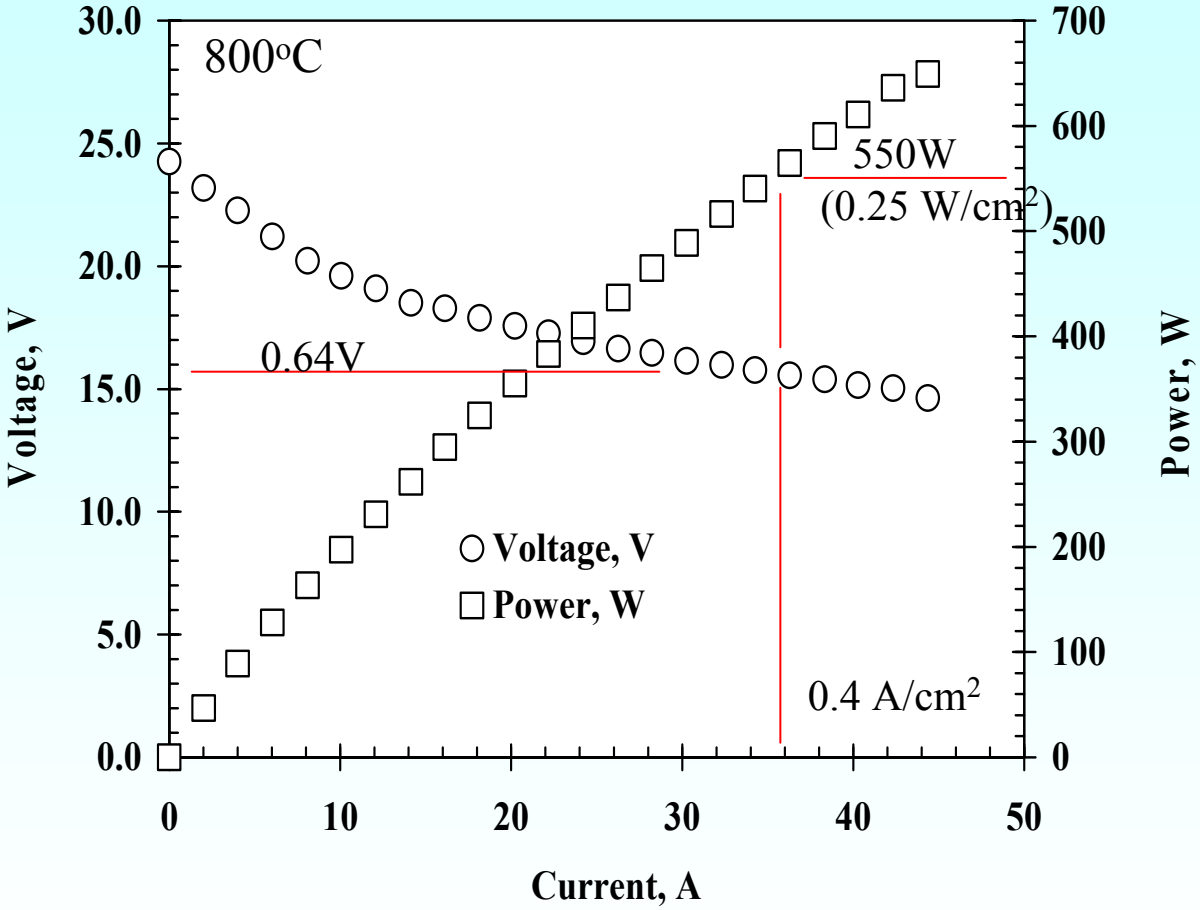
4-cell 2"x2" stack, 25 cm^2 active area per cell,
operating at 800°C; air is the oxidant and hydrogen is the fuel.
The maximum power degradation rate is less than 5% over 1000 hours.

Stack Thermal Cycling (T.C.) – 4-cell 4”x4” stack



(-) Wet H_2, Ni+YSZ/YSZ/LSM+YSZ, Air (+), voltage degrades less than 5% within the 1st 8-TC

Reformate Fuel – 25 Cells 4” x 4” Stack



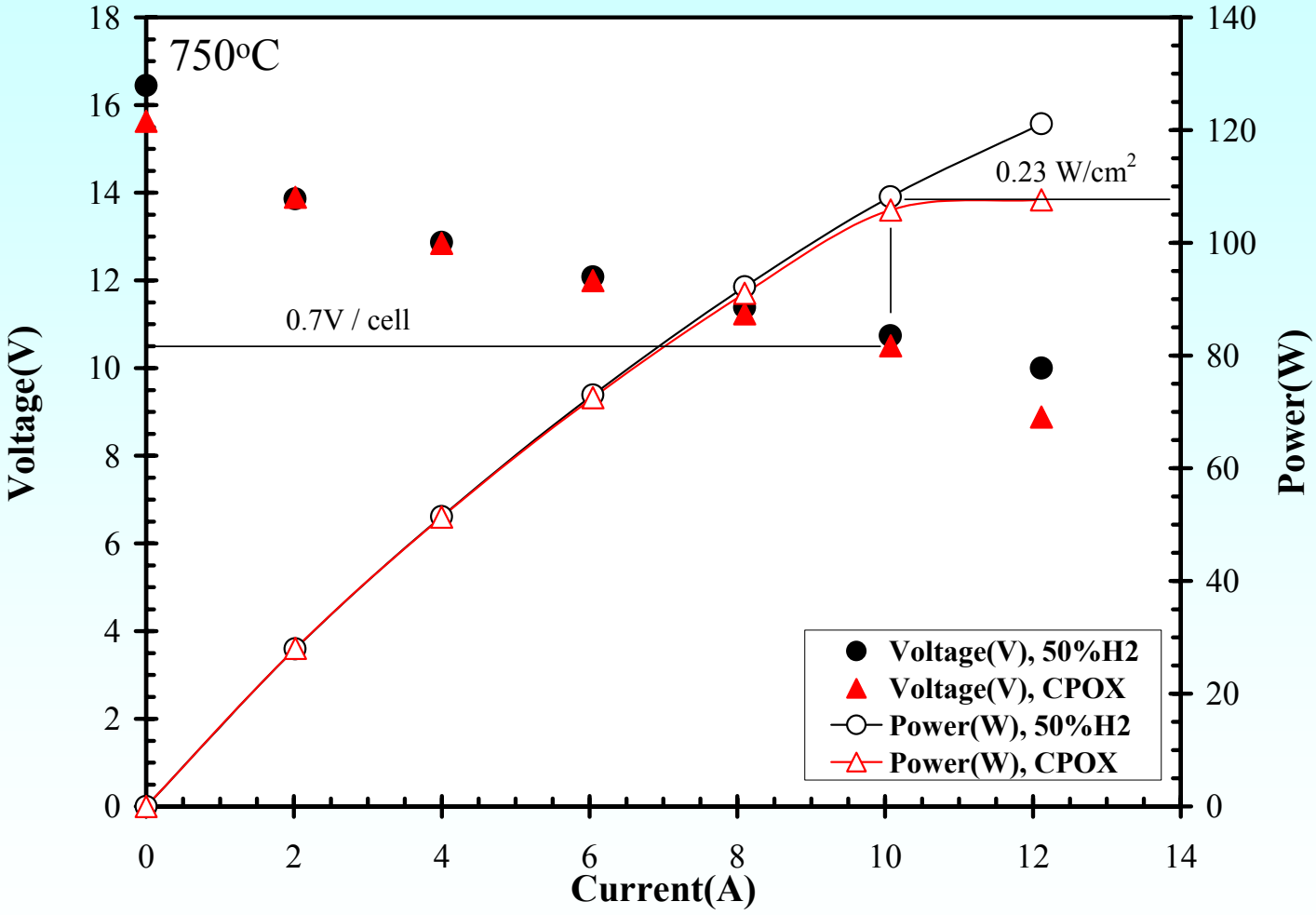
Dry: 76.6 % H_2, 15.3 % CO, and 8.1 % CO_2

Wet: 55.8% H_2, 11.1% CO, 5.9% CO_2, and 27.2% H_2O

Uf/Ua=40/40

Reformate/air

CPOX – 15 Cells 2” x 2” Stack

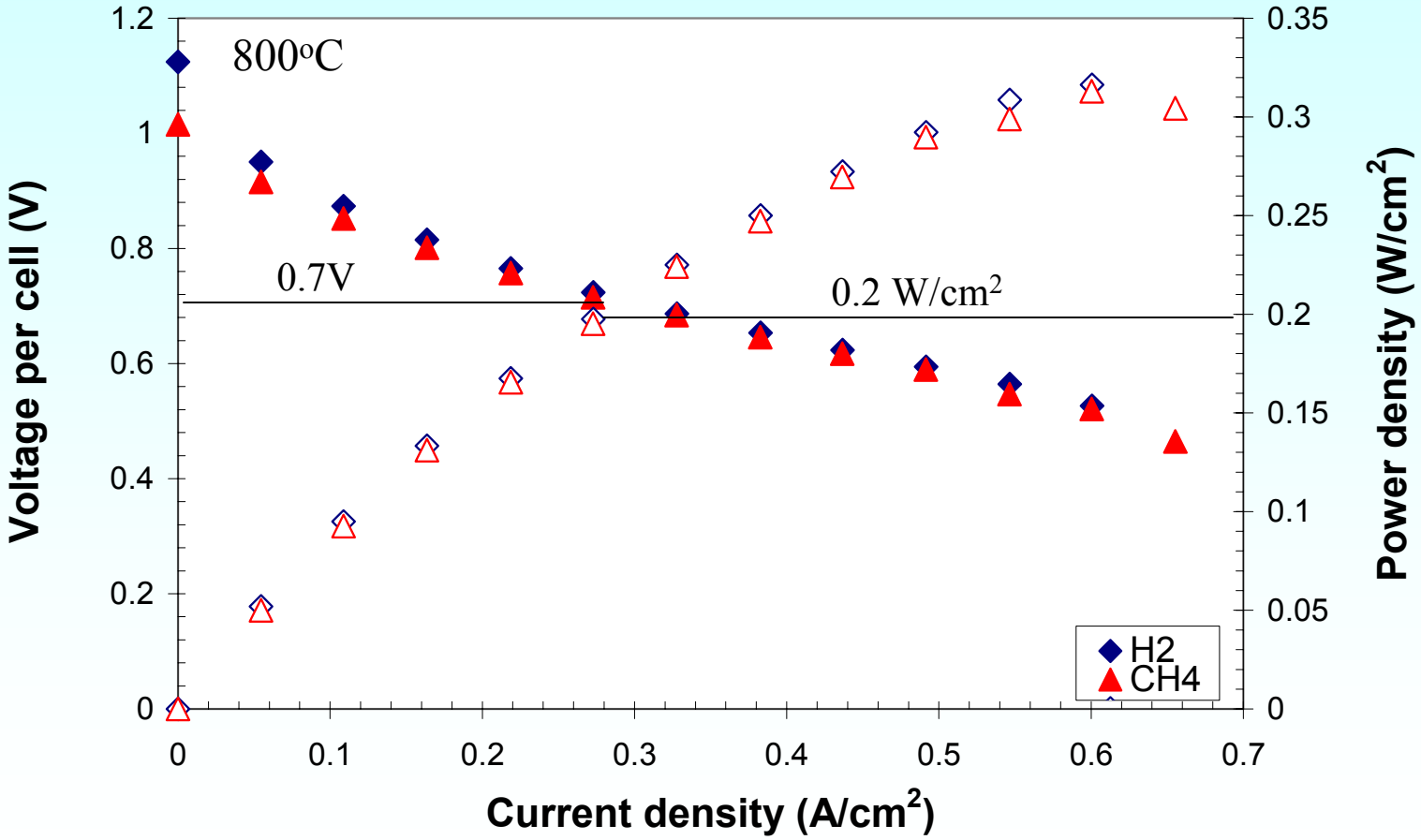


CPOX: 25.7% H_2, 25.6% CO, 4.94% CO_2, 43.76 N_2

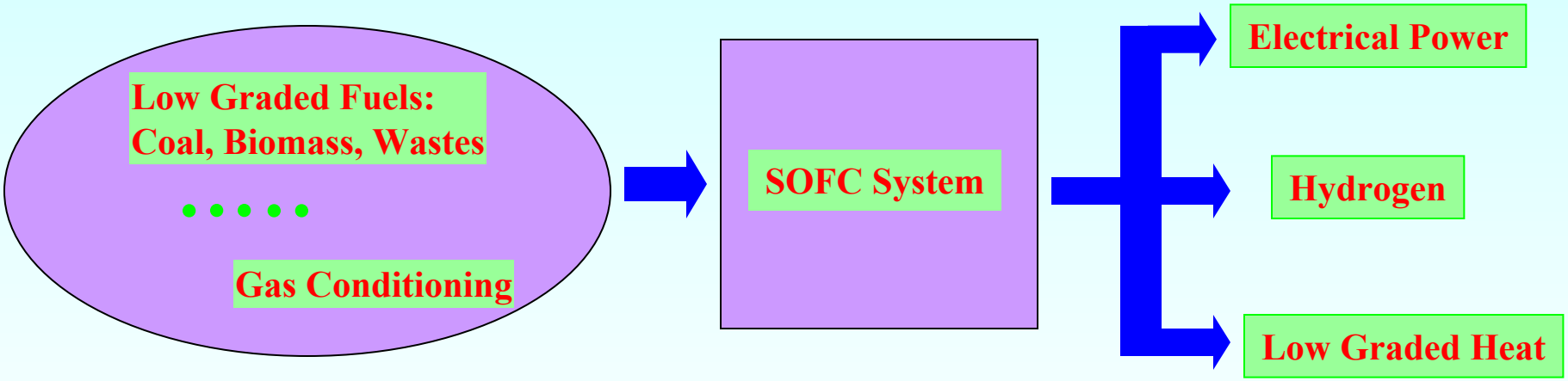
Uf/Ua=50/50

Methane Fuel (100% DIR) – 10 Cells 4” x 4” Stack

Stack Performance Comparison Using Different Fuels (40/40): H_2 vs CH_4 (100% DIR)



Advanced SOFC Combined System Study



Gasification system **SOFC System** **Products**

Summary of MSRI SOFC R&D Activities

- **MSRI has been one of pioneers leading the SOFC R&D**
- **MSRI SOFC technology and capability**
- **Looking for opportunity to collaborate with other research parties**

Thank You