Farmingdale State College

IRTT

Institute for Research and Technology Transfer

Hydrogen Fuel Cell Research and Education Center

Hydrogen, Methanol and Ethanol PEM Fuel Cell Development at IRTT

Hazem Tawfik, Ph.D., P.E., C.Mfg.E.
SUNY Distinguished Service Professor

Director of the Institute for Research and Technology Transfer
Farmingdale State College – State University of New York

Guest Scientist

Brookhaven National Laboratory (BNL)

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IRTT Mission Statements

- Support the regional economic growth through research & development and transfer of new technologies to industry
- Enrich the educational experience of students with real world applications and modern technologies

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IRTT's VISION

To develop a National Center of Excellence

For Fuel Cell

Applied Research and Education

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IRTT's MOTIVATION

Renewable hydrogen generated from wind, solar, biomasses and nuclear energy holds an excellent potential to solve our national energy problem while maintaining our clean healthy environment free of pollution and eliminates greenhouse effect and global warming

IRTT Organizational Chart

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BOARD OF DIRECTORS

Dr. Hubert Keen, President
Dr. Lucia Cepriano, Acting Provost
Dr. Kamal Sahrabi, Dean School of Engineering Technologies
Dr. Devinder Mahajan, Professor and Co-Director SBU and Group Leader, BNL
Dr. Henry Sikorski, Institutional Advancement
Dr. Jack Winn, Chairman, Applied Mathematics Department
Mr. Donald Middleton, President, Route 110 Redevelopment Corporation
Mr. Noel Blackburn, Program Manager, BNL

Nominated Directors:

Dr. Emilio Mendez, Director, Center for Functional Nanomaterials, BNL
Mr. David Law, Chairman, Long Island Power Authority (LIPA)
Mr. Kenneth Morrelly, President, Long Island forum for Technology
Mr. Frank Auto, VP, EDO Corp.
Mr. Robert Klein, VP Northrop Grumman Aerospace Corp.

IRTT Research Faculty & Staff

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RESEARCH FACULTY AND STAFF

Dr. Hazem Tawfik, Director IRTT
Dr. Charles Rubenstein, Visiting Professor IRTT
Dr. Kamel El-Khatib, Visiting Professor IRTT
Dr. Yeong Ryu, Assistant Professor MET
Mr. Nick Yaron, Manager Industrial Relations
Mr. Jeff Hung, Technical Specialist MET and IRTT
Mr. Joel Yeol, Visiting Research Engineer
Mr. Razwan Arif, Visiting Research Technologist
Mr. Carl Vogel, Visiting Research Technologist

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Areas of Research and Development at IRTT

More than 60 Senior Projects, Two Master Degrees Thesis Projects, and Thirty five Companies were benefited of IRTT's R&D Technologies in the following areas:

- Polymer Electrolyte Membrane (PEM) Fuel Cells
- Robotics and Automation
- Computer Aided Engineering and Finite Element Analysis
- Steriolithography and Rapid Prototyping
- Metal Thermal Spray Technology

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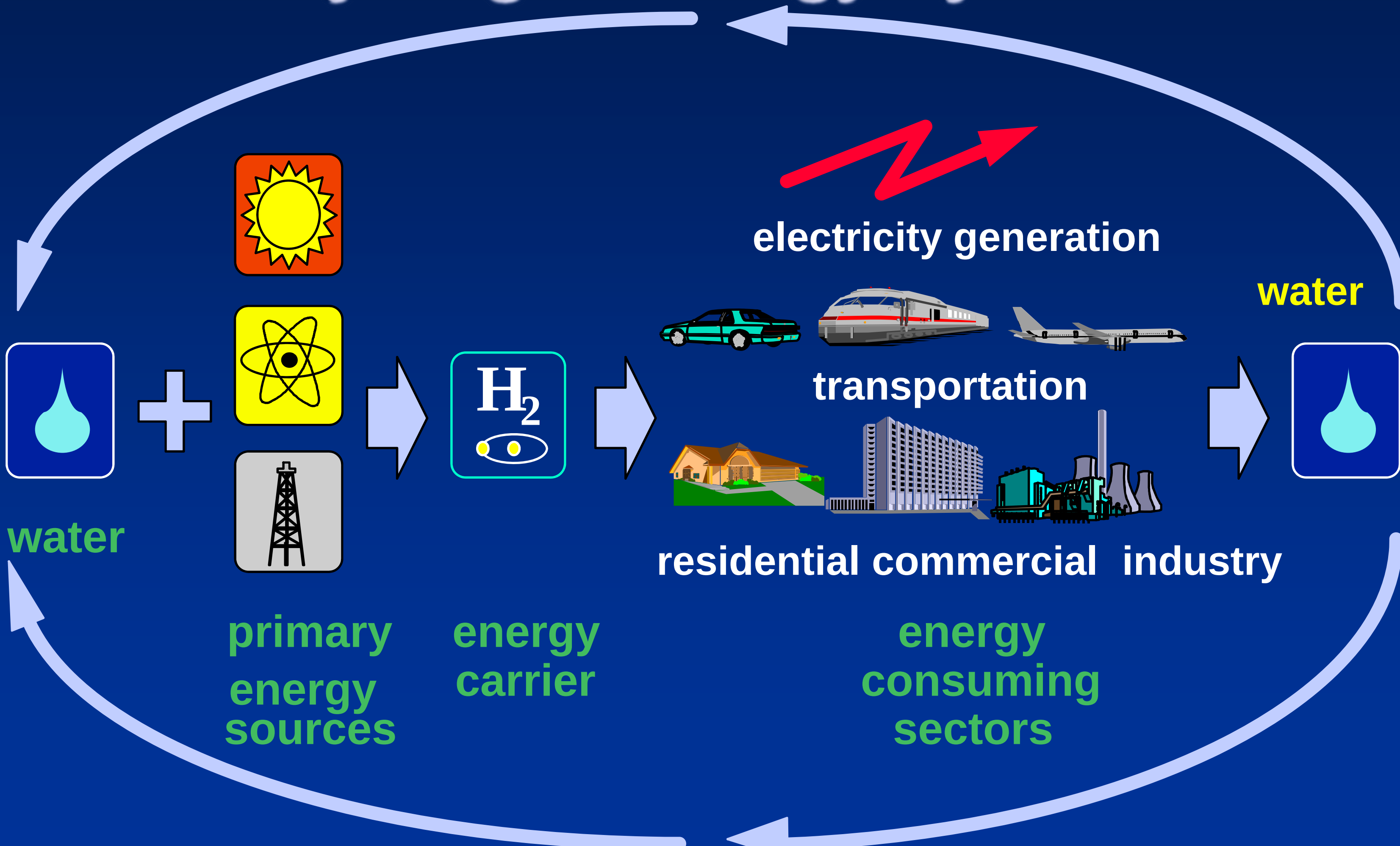
Hydrogen Economy or Hydrogen Energy System



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Research is a Powerful Educational Tool

IRTT's 2006-2007
Areas of Research and Educational Programs

Fuel Cells:

- Metallic Bipolar Plate and Stacks
- 1 kW Hydrogen Fuel Cell Power Stack
- Methane and Ethane Fuel Cells

Renewable Energy Projects:

Solar/Hydrogen Homes (Full size & Model)

Bio-Diesel Vehicles

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Metallic Bipolar Plates

1. **Development of durable, cost effective, lightweight, and highly conductive Metallic Bipolar Plates for Hydrogen Fuel Cells**

Two Patents were issued for Dr. Tawfik and Mr. Hung

Research Team:

Kamel El-Khatib, Jeff Hung, Hazem Tawfik, and Devinder Mahajan

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Fuel Cells

2. Water Management and Humidity Control Systems inside the Fuel Cell

Research Team:

Joe Yoel, Yeong Ryu, and Hazem Tawfik

BNL FaST 2007 Projects
Noel Blackburn, Manager

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3. Fuel Cell Humidity Optimization and Water Management in Polymer Electrolyte Membranes (PEM)

Research Team:

Andrew Fasano, Hazem Tawfik, and Devinder Mahajan

4. Thermal Management Inside the Fuel Cell, Measurement of Temperature Distribution, and Thermal Management Control System of PEM Power Stack

Research Team:

Robert Schulz, Hazem Tawfik, and Devinder Mahajan

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1 kW Fuel Cell

5. Design and Development of One kW Fuel Cell Power Stack with Cooling System and Balance of Plant

Research team:

Jeff Hung, Hazem Tawfik, Nick Yaron and Charles Rubenstein

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BNL SULI Program

6. Development of direct Methanol and Ethanol Fuel Cells

Research team:

Raja Crowley, Glenn Musano, Hazem Tawfik, and Devinder Mahajan

(Partial funding by BNL)

Solar Power

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7. Development of Solar Cells using thermally sprayed Silicon Carbide and Nickel Chrome

Research team:

Ken Gilmore, John Turner (National Renewable Energy Laboratory), Dr. Kamel El-Khatib and Hazem Tawfik

8. Energy and System Analysis on a Hybrid Hydrogen and Solar Powered Small House Model

Research team:

Razwan Arif and Hazem Tawfik

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Hybrid Vehicles

9. Development of Bio-Diesel Vehicles

Research team:

Carl Vogel and Hazem Tawfik

10. Further Development of a Hybrid Hydrogen Fuel Cell small vehicle and Go Cart

Research team:

Razwan Arif, Nick Yaron and Hazem Tawfik

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What is a Fuel Cell?

- Fuel cell is an electrochemical devise that is fed by hydrogen and oxygen and produces electric power, heat, and clean drinkable water
- Fuel cells are two times more efficient than internal combustion engines
- Fuel cells have excellent potential for economic viability

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Types of Fuel Cells

Fuel Cell Type	Electrolyte	Anode Gas	Cathode Gas	Temp.	Efficiency
Proton Exchange Membrane (PEM)	Solid Polymer Membrane	Hydrogen	Pure or Atmospheric Oxygen	75 C 180 F	35-60%
Alkaline (AFC)	Potassium Hydroxide	Hydrogen	Pure Oxygen	Below 80 C	50-70%
Direct Methanol (DMFC)	Solid polymer membrane	Methanol solution in water	Atmospheric oxygen	75 C 180 F	35-40%
Phosphoric Acid (PAFC)	Phosphorous	Hydrogen	Atmospheric oxygen	210 C 400 F	35-50%
Molten Carbonate (MCFC)	Alkali-Carbonates	Hydrogen, methane	Atmospheric oxygen	650C 1200 F	40-55%
Solid Oxide (SOFC)	Ceramic Oxide	Hydrogen, methane	Atmospheric Oxygen	800-1000 C 1500-1800 F	45-60%

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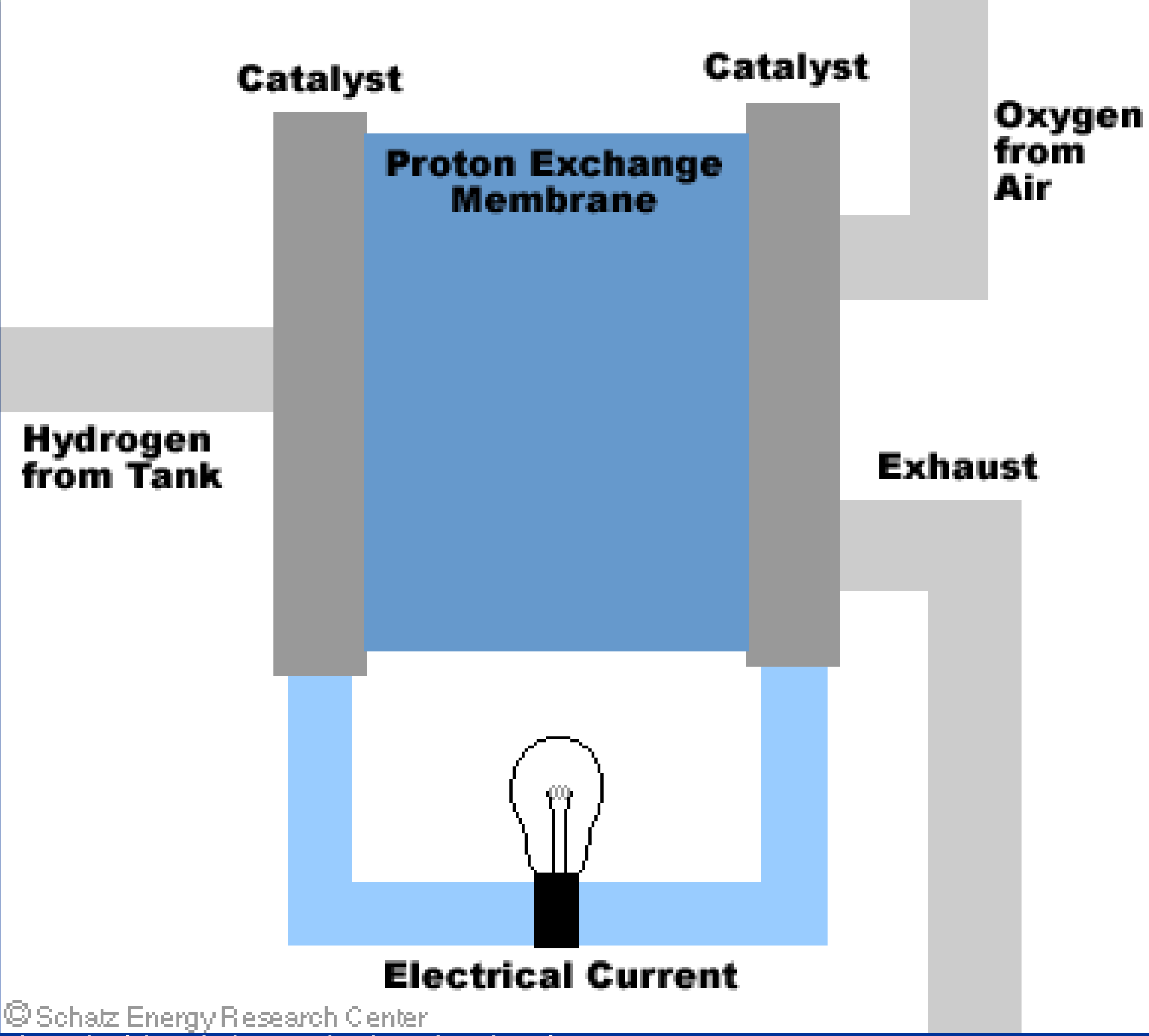
PEM Fuel Cell Theory of Operation



- http://www.humboldt.edu/~serc/animation.html

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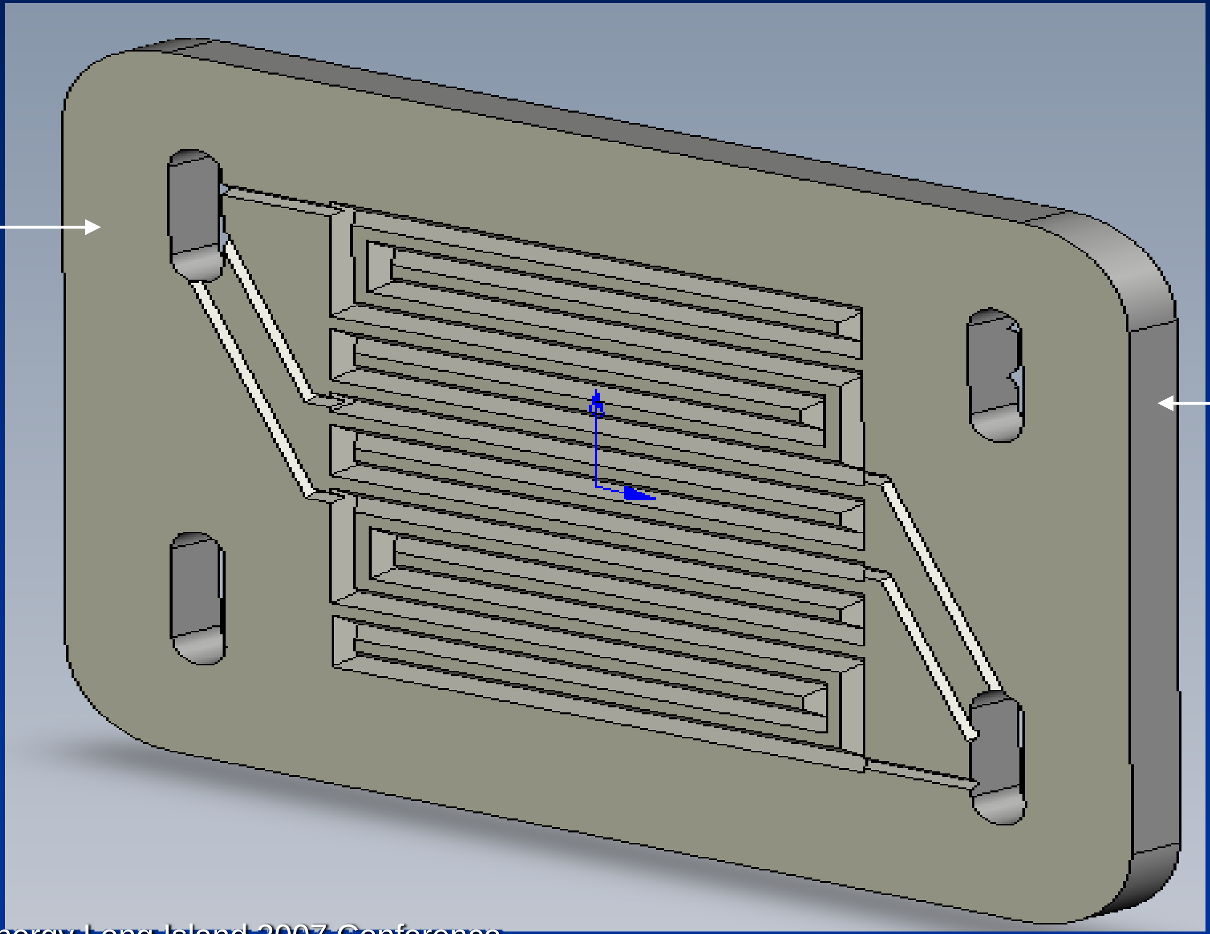
What is a bipolar Plate?

- **It is the backbone of a fuel cell power stack**
- **Acts as the current collector in the fuel cell environment**
- **It provides conduits for the reactant gases**
- **Must be highly conductive and corrosion resistant**

Our IRTT technology

"makes metallic bipolar plates endure and perform more efficiently than graphite plates."

Carbide based Corrosion Resistant Coating



Metallic bipolar plate

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Department of Energy (DOE) PEM Fuel Cell Targets

Table 3: Technical Targets: Bipolar Plates

Characteristic	Units	Status 2004	2010
Cost	\$/kW	10	6
Weight	kg/kW	0.36	<1
H_2 Permeation Flux	$cm^3\ sec^{-1}\ cm^{-2}$ @ 80°C, 3 atm (equivalent to <0.1 mA/cm^2)	$<2 \times 10^{-6}$	$<2 \times 10^{-6}$
Corrosion	$\mu A/cm^2$	<1 [a]	<1 [b]
Electrical Conductivity	S/cm	>600	>100
Area specific resistance[c]	Ohm cm^2	<0.02	0.01
Flexural Strength	MPa	>34	>4(crush)
Flexibility	% deflection at mid-span	1.5 to 3.5	3 to 5

[a] Based on coated metal plates.
[b] May have to be as low as 1 nA/cm^2 if all corrosion product ions remain in ionomer.
[c] [illegible] contact resistance

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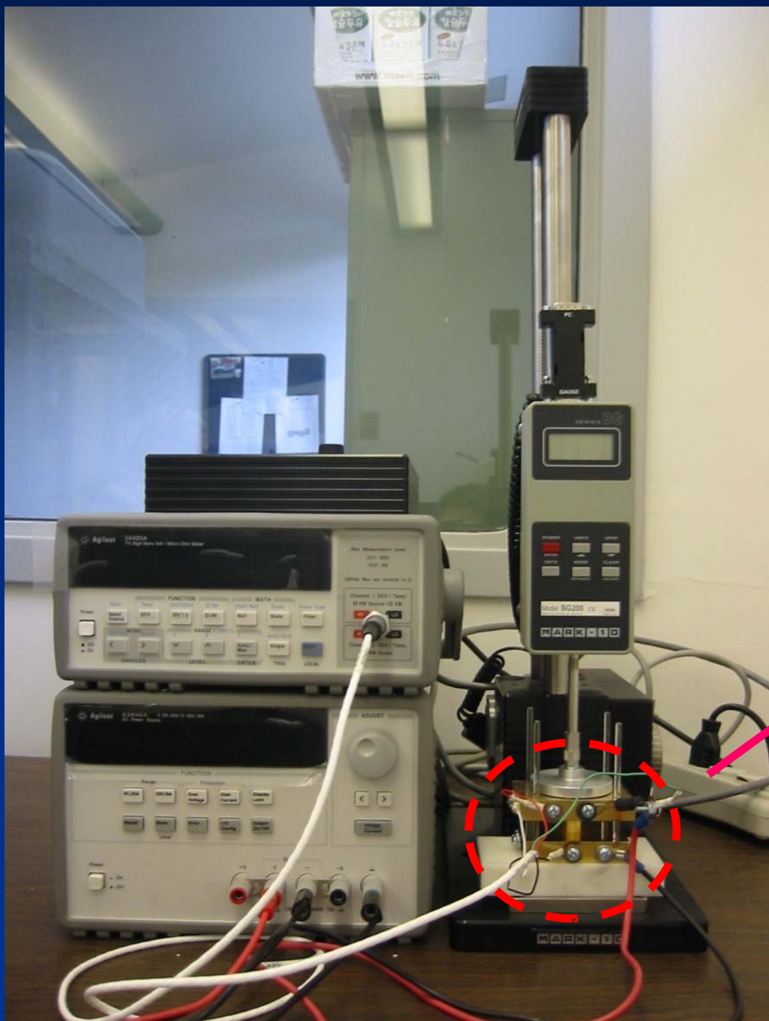
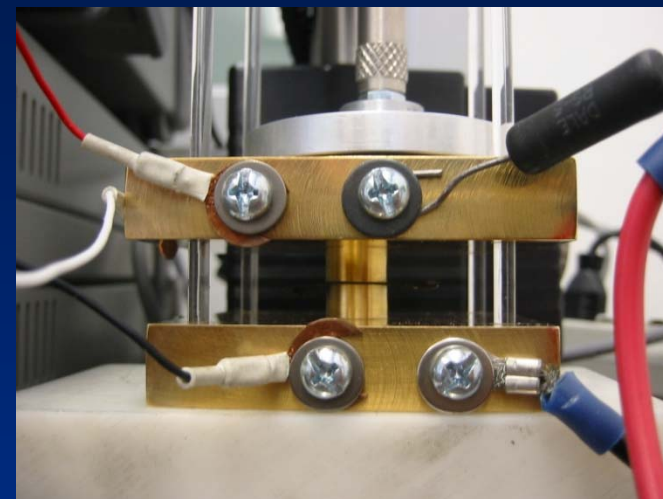
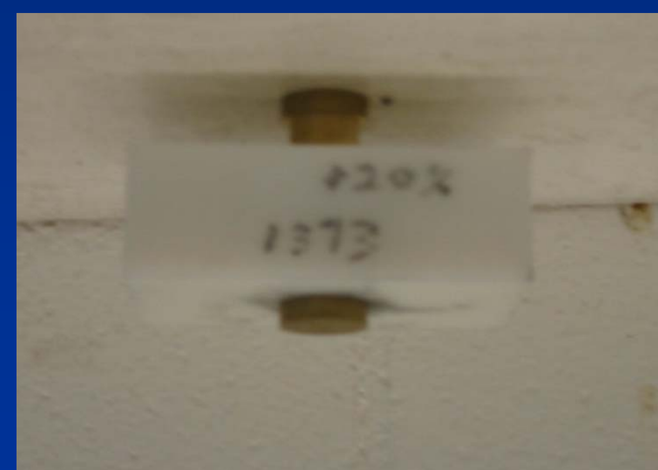
Interfacial Contact Resistance Measurement Setup





Coupon Test Fixture



Digital press, power supply, & m ohm meter

Powder Test Fixture

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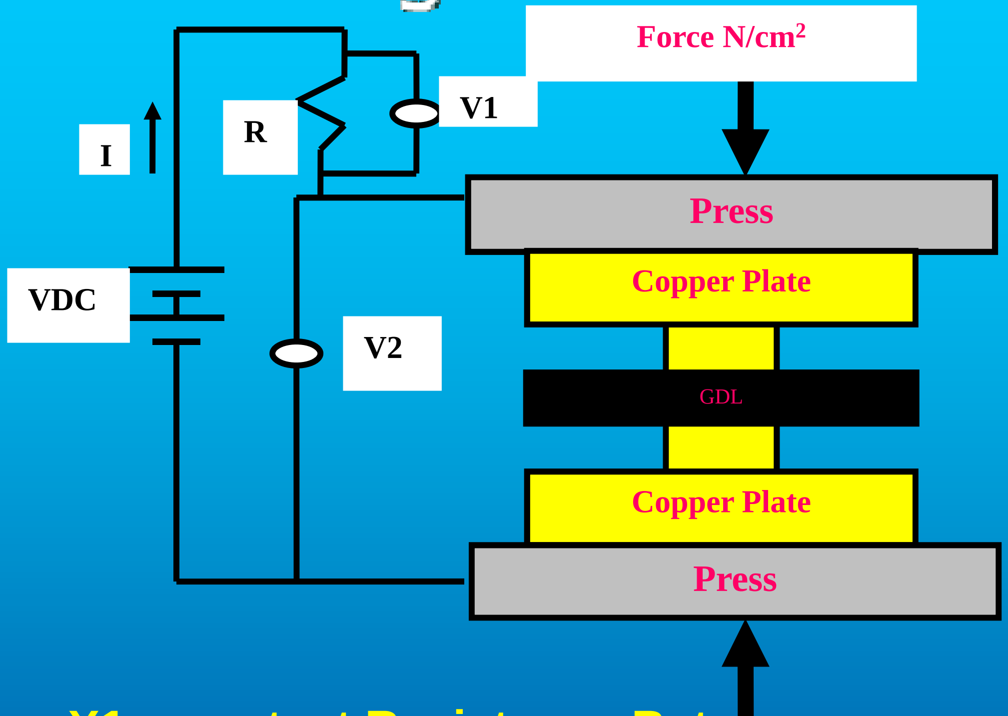

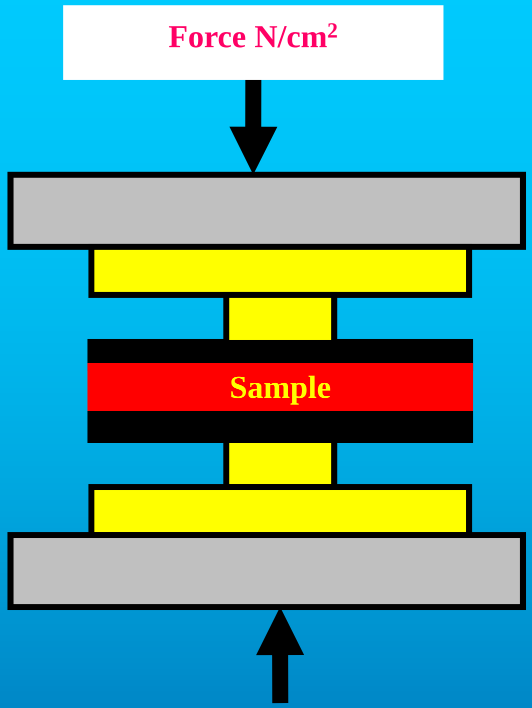

X1 = contact Resistance Between copper and GDL
X2 = Contact Resistance Between Bipolar plate and GDL

V1 = I * R
when R = 1 ohm then V1 = I

V2 = I * R_{cell} = V1* R_{cell}

R_{cell} = V2 / V1

R1 = x1+x1 =2x1

R_{cell} = x1+ x2 + x2+ x1=2x1+2x2 = R1 + 2x2

ICR = (R_{cell}- R1)/2

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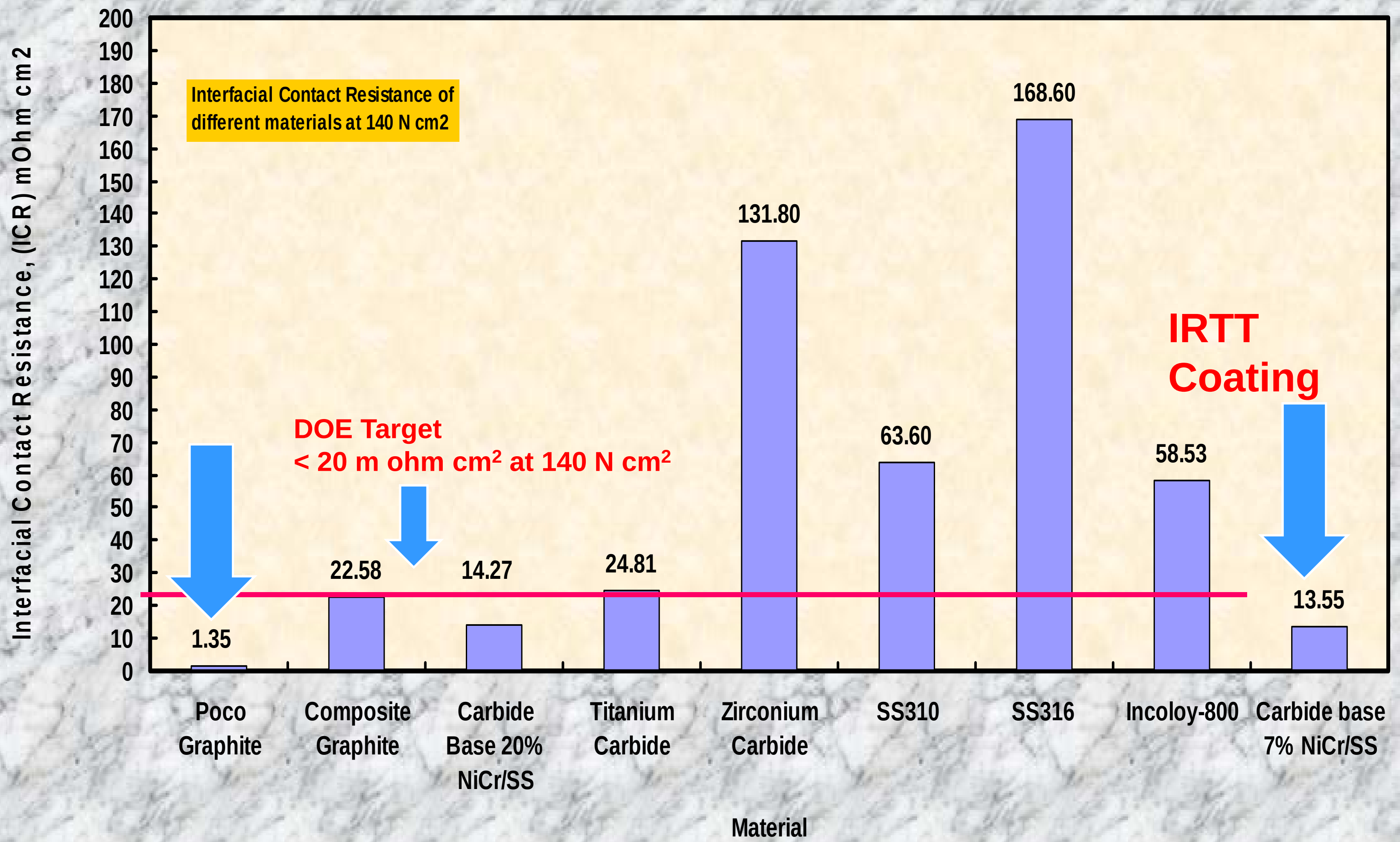

Interface Contact Resistance (ICR) for Different Materials with Gas Diffusion Layer (GDL)

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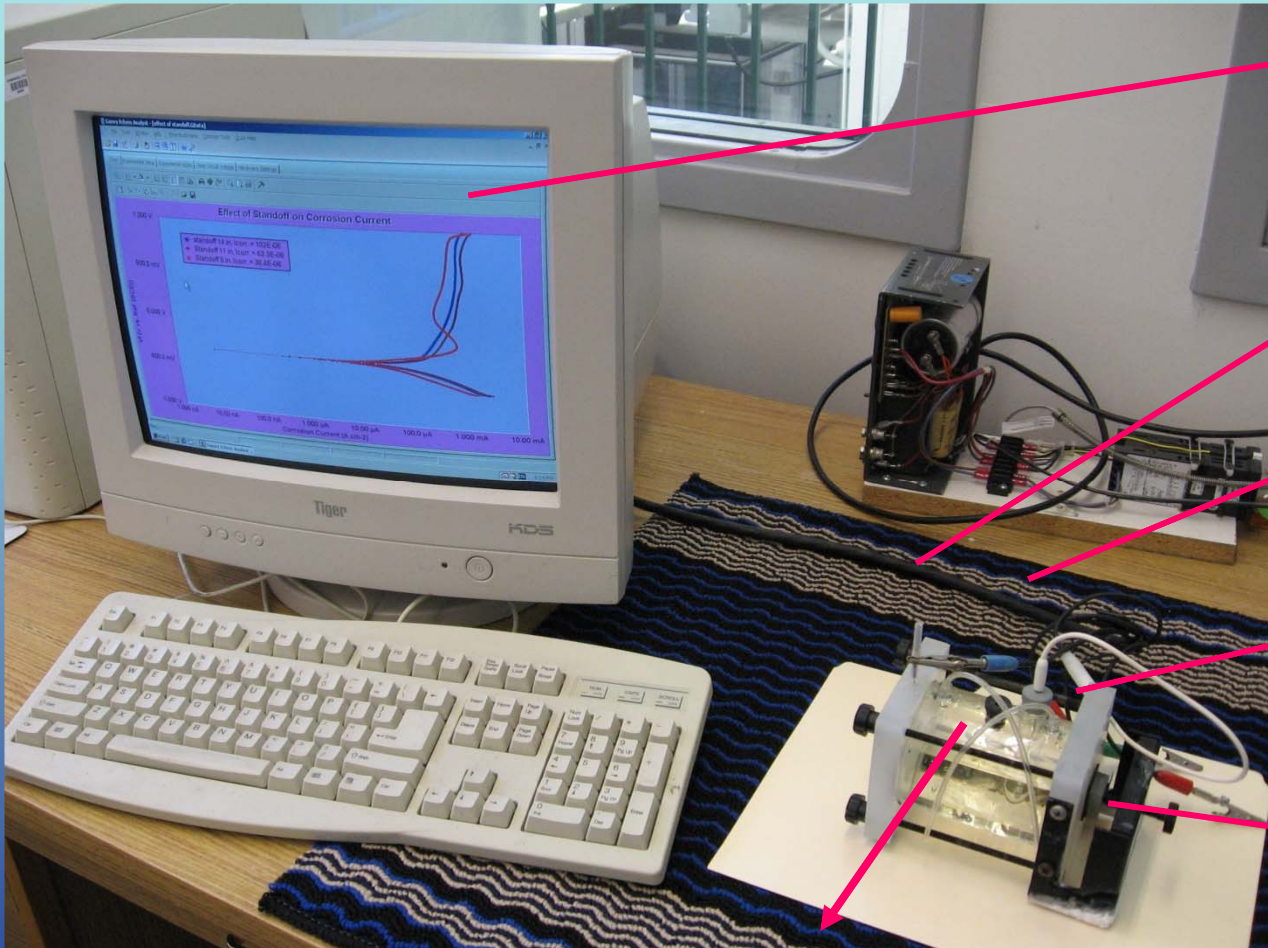
Corrosion Measurement Setup



Corrosion Analysis Software

Counter Electrode

SCE reference Electrode

Working Electrode

Corrosion cell Kit

Test Solution 0.5 M H_2SO_4 + 200 ppm HF @ room temperature

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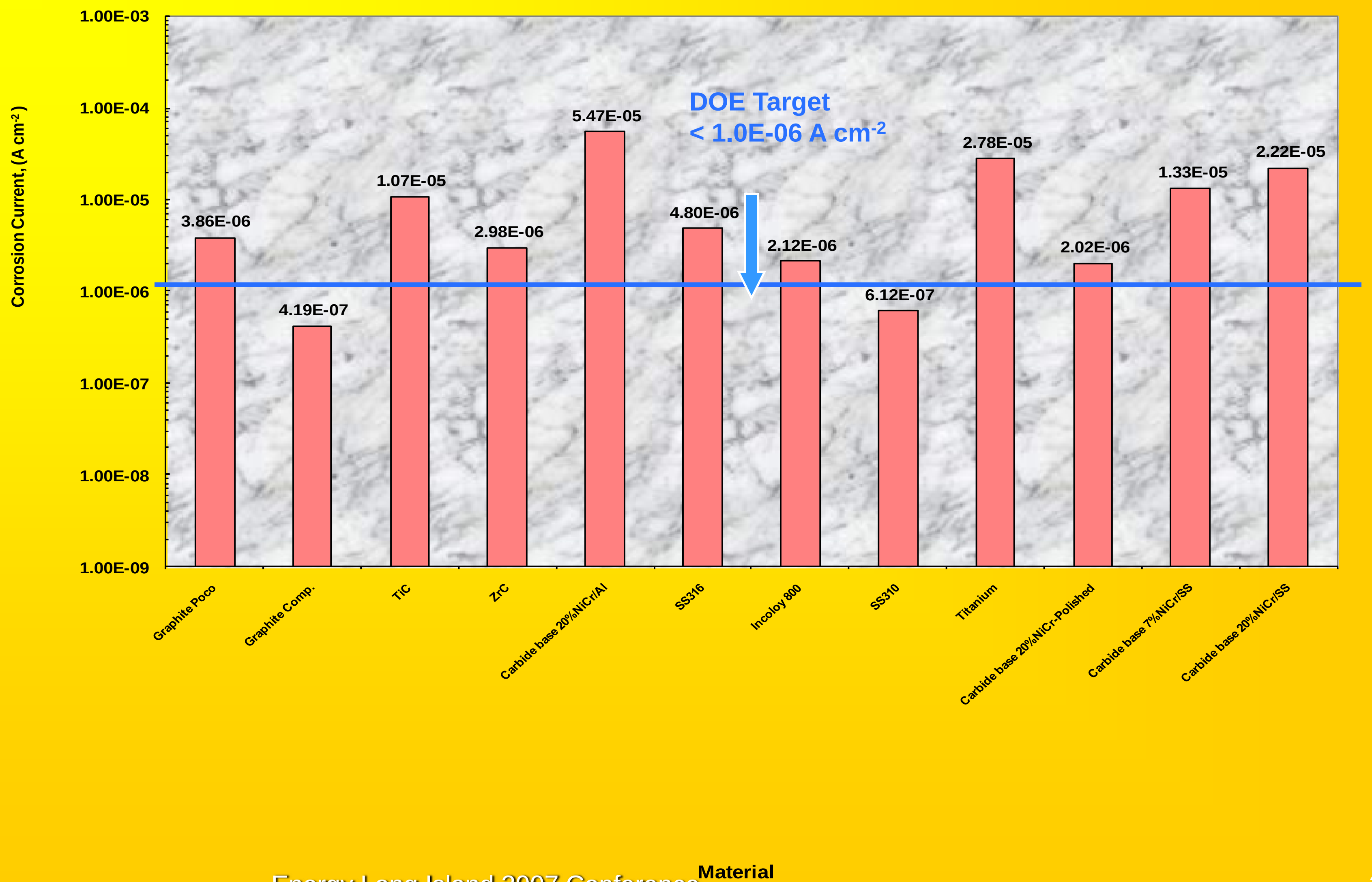

Corrosion Current of Different Bipolar Plate Materials For PEM Fuel Cell

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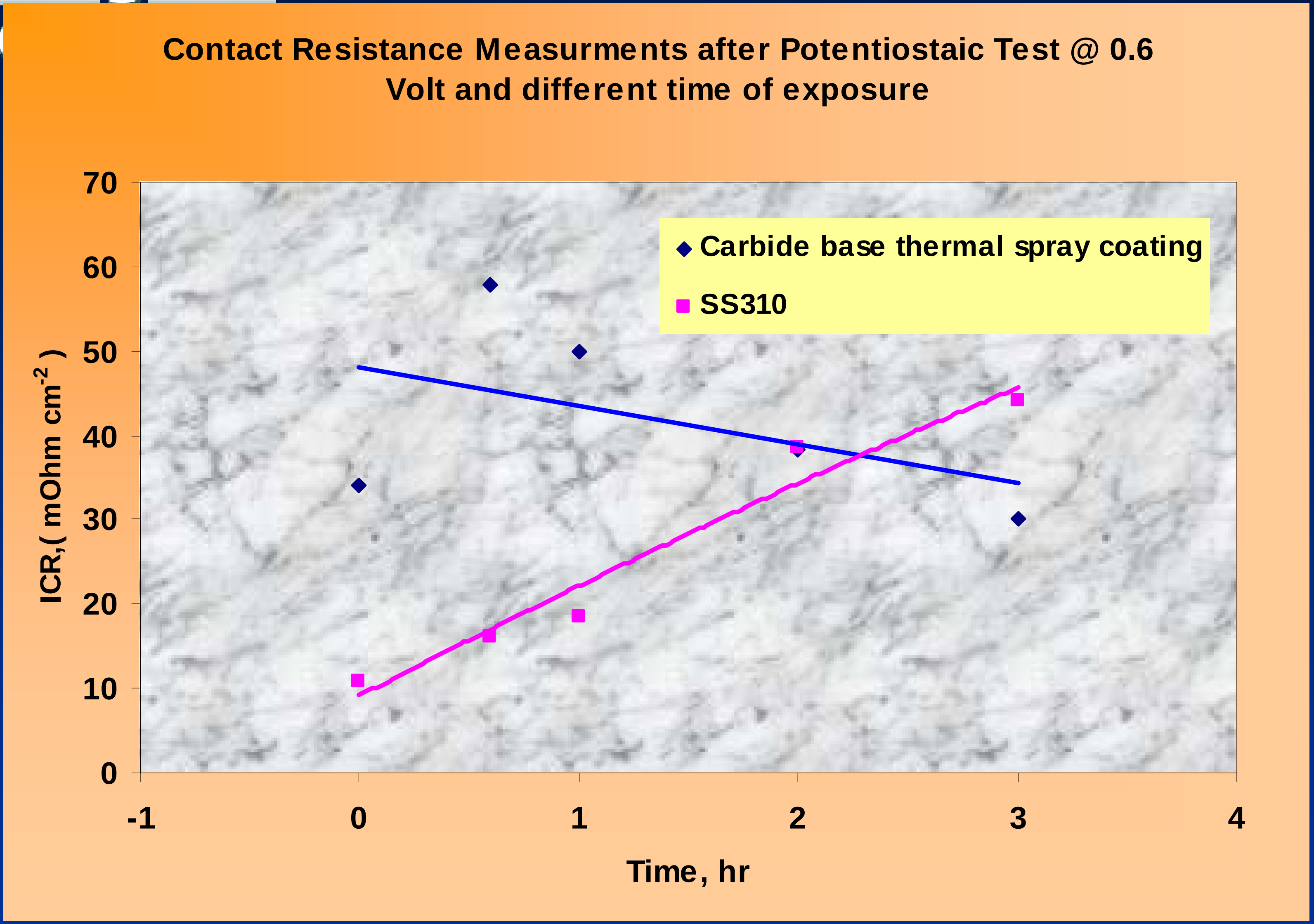

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CNC Machining Center

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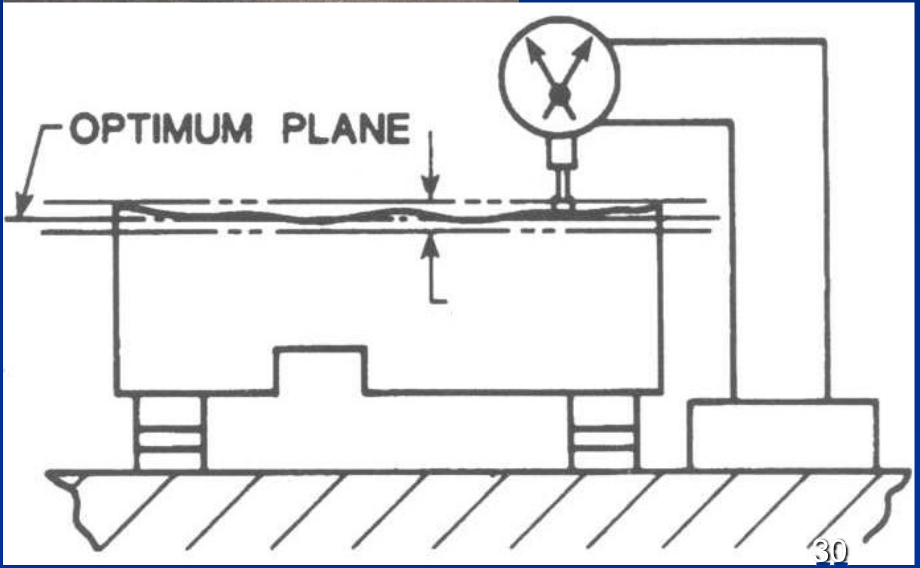
Equipments for flatness measurements



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55 Ton Press for MEA Fabrication

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High Velocity Oxygen Fuel (HVOF) Thermal Spray Sys

MASK

AIR COOLING

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• Therma

Thermal spray operating parameters

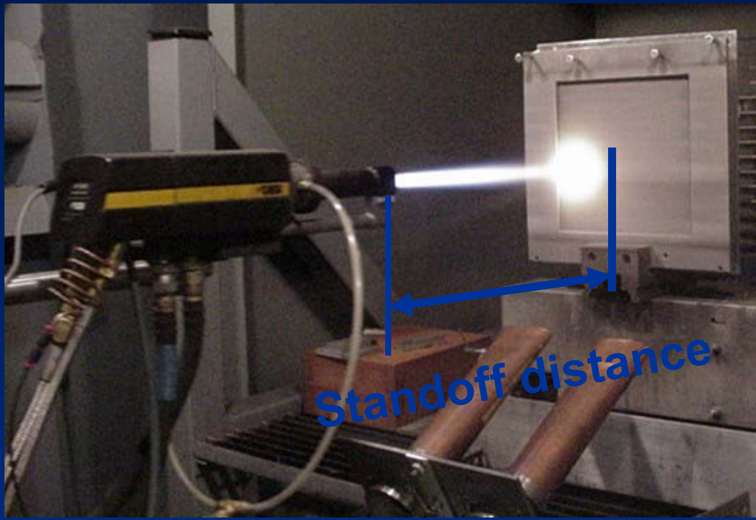
- Blank Stainless Steel 310
- Sprayed Carbide Base , 20 % NiCr
- Thermally Sprayed Pure Carbide Base

❖ Powder Flow Rate 5, 7.5 and 10 lb/hr

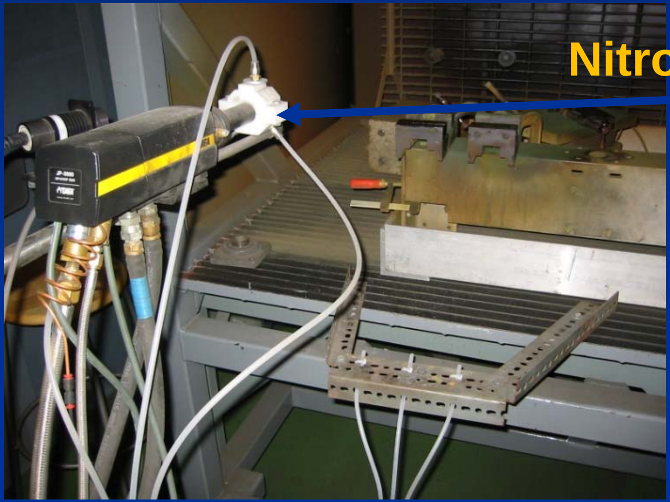
❖ Standoff Distance 8, 11 and 14 in.

❖ Nitrogen Shielding

Tested materials



Thermal spray



Nitrogen Shielding

Powder Feeder

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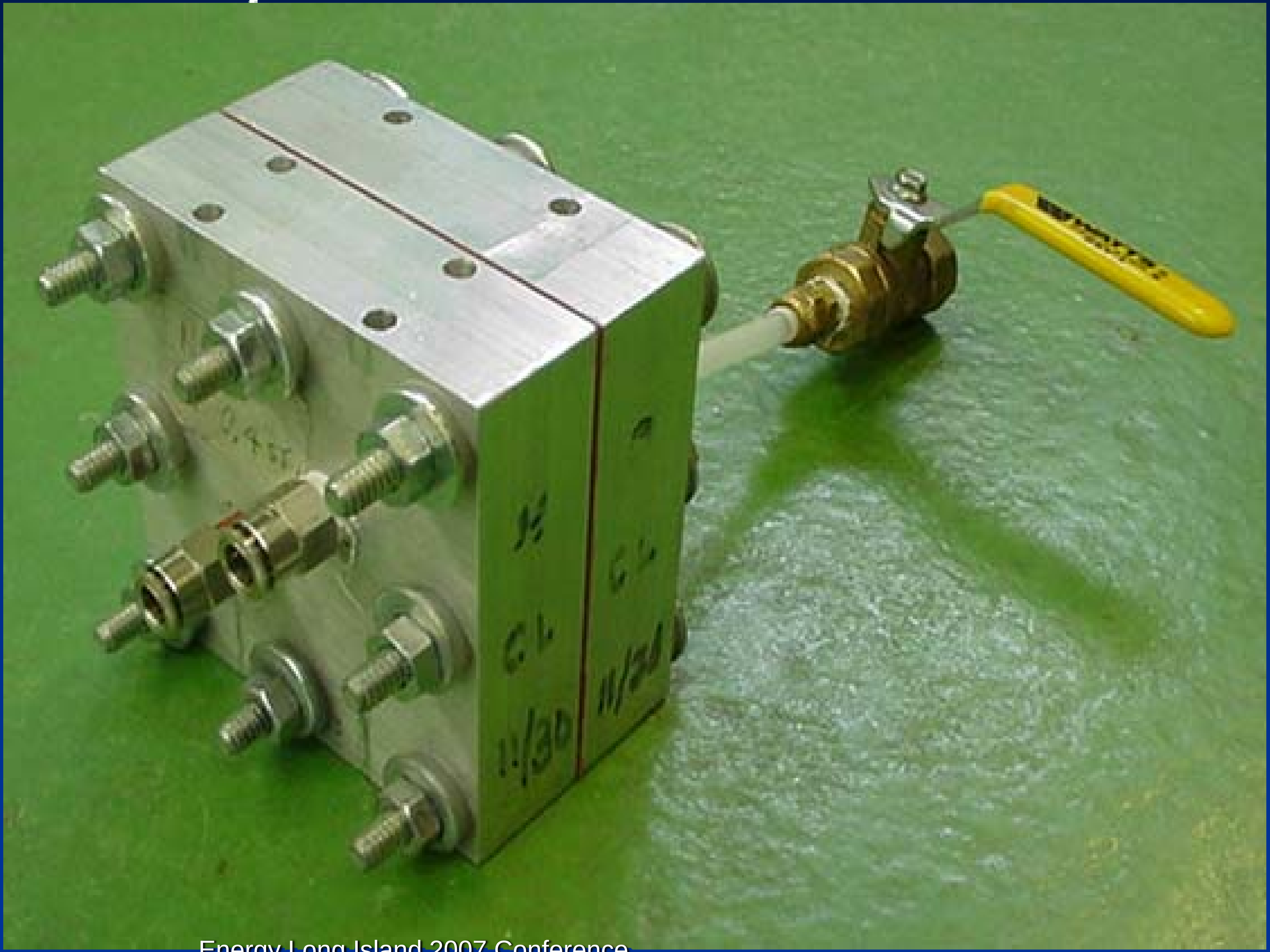
Single Cell Aluminum Bipolar Plates



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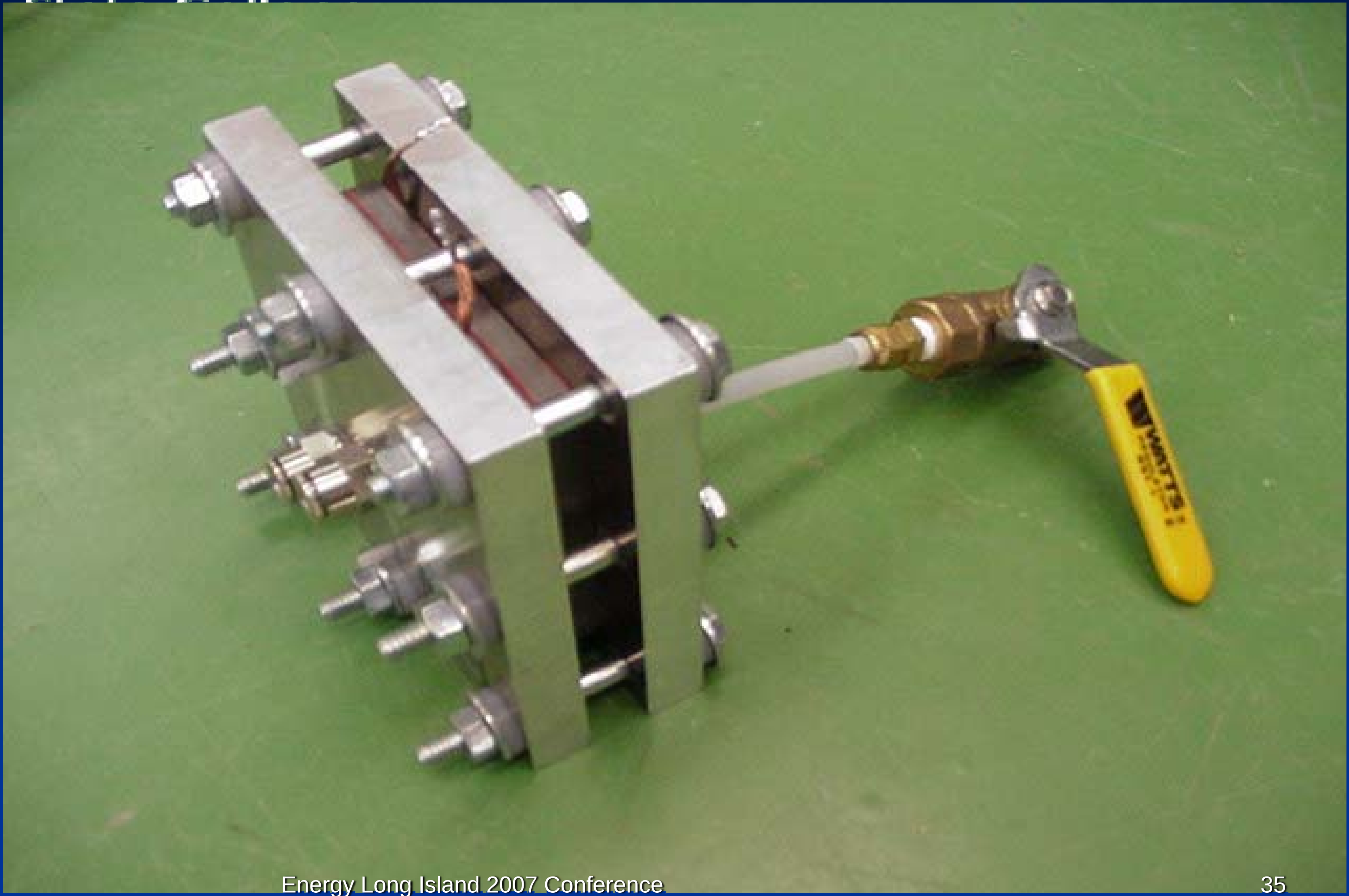
Single Cell Graphite Bipolar Plates



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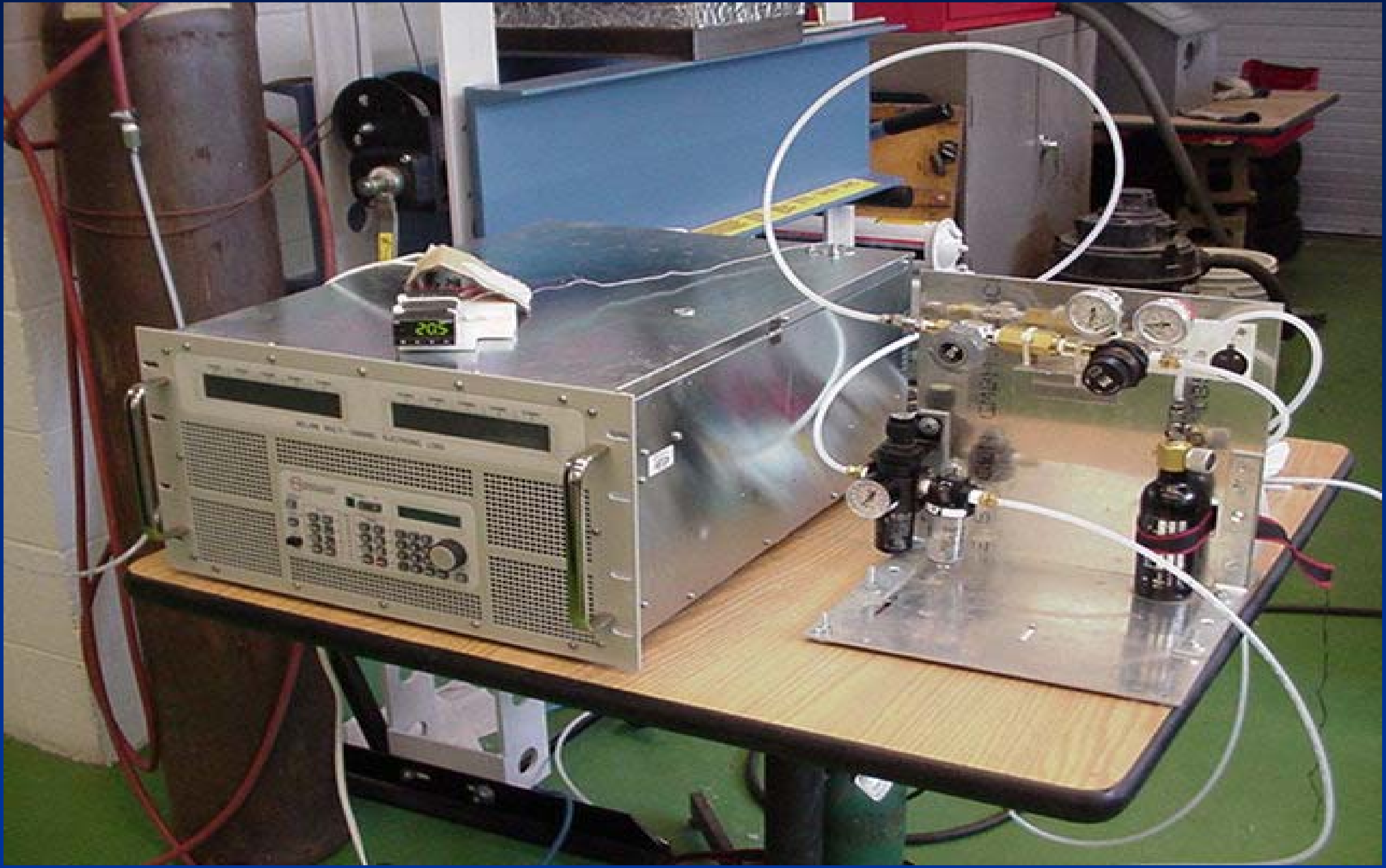
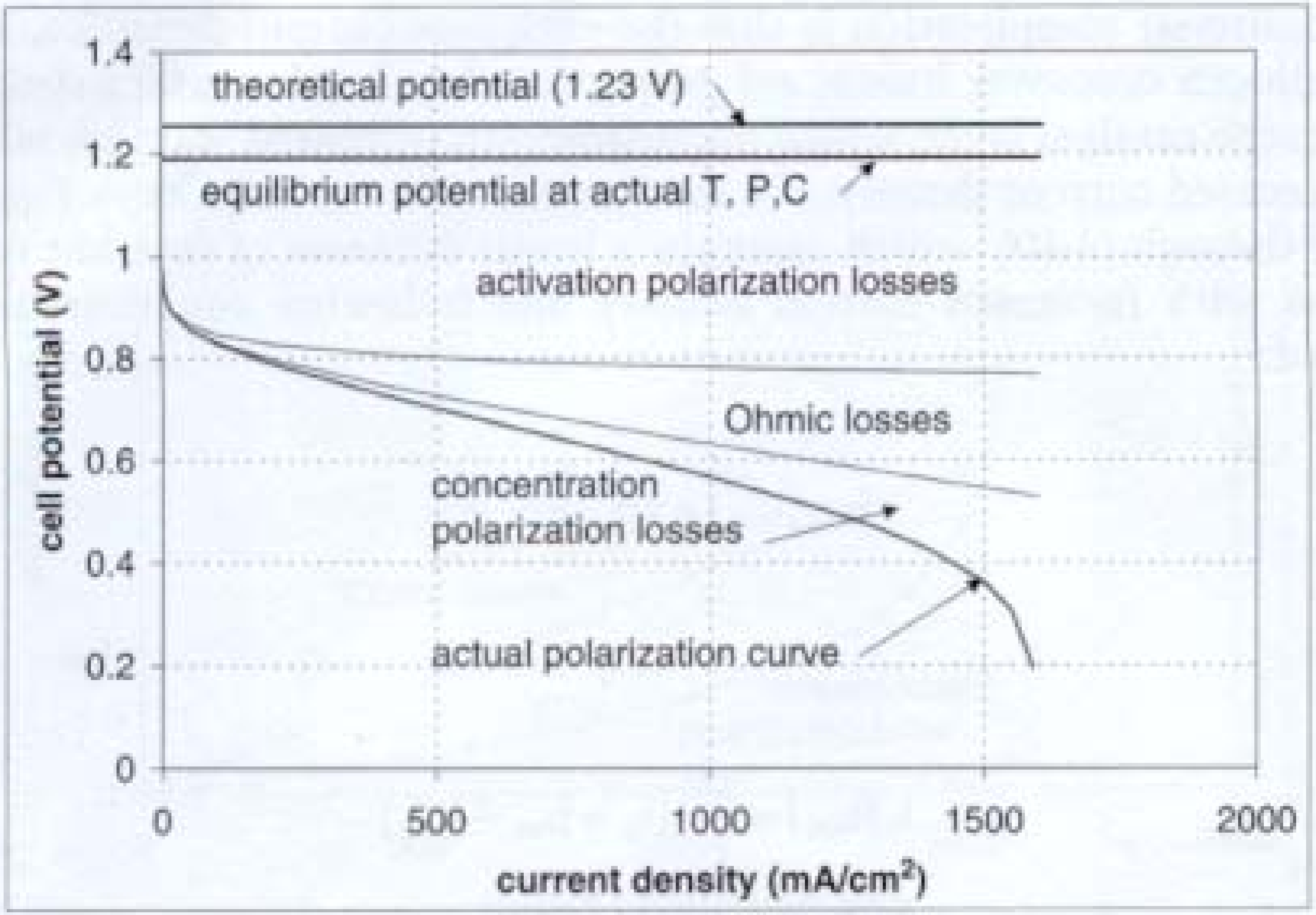
Variable Loading Testing M/C



Typical Polarization Curve



Voltage losses in fuel cell and resulting polarization curve.

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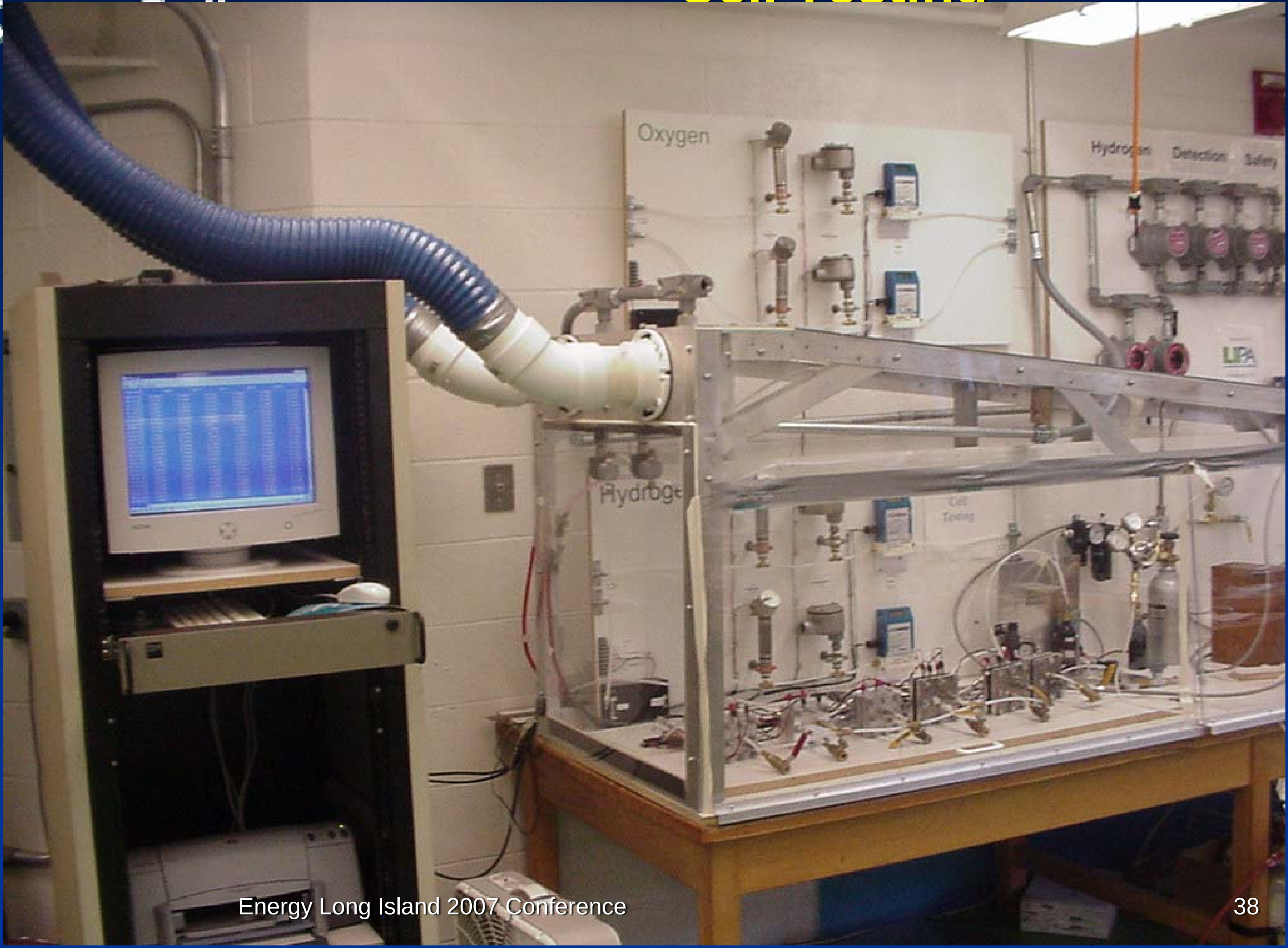
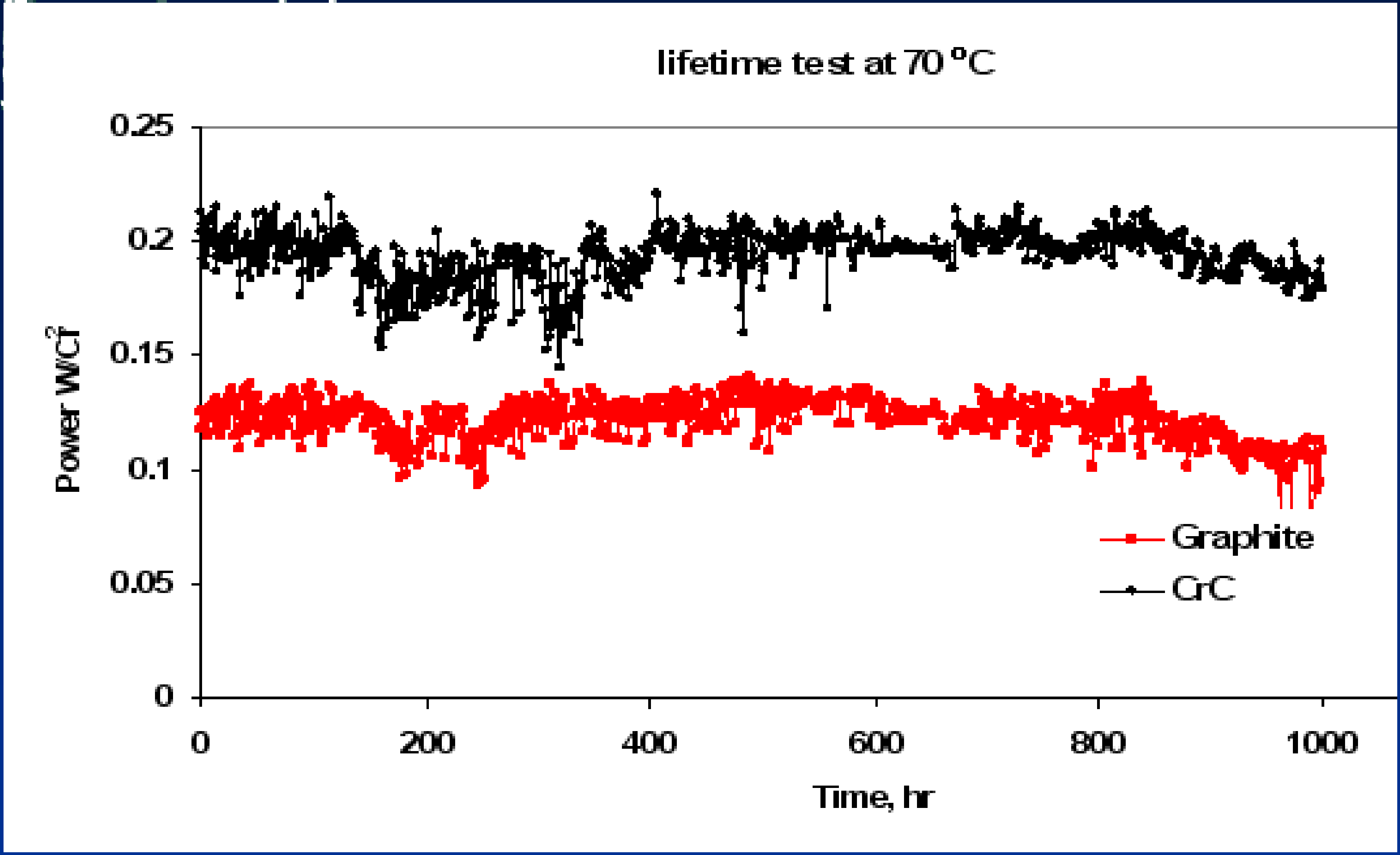
Hydrogen Safety System For Fuel Cell Testing





Life time testing of graphite composite and carbide based coated aluminum plates under cyclic loading and 70oC

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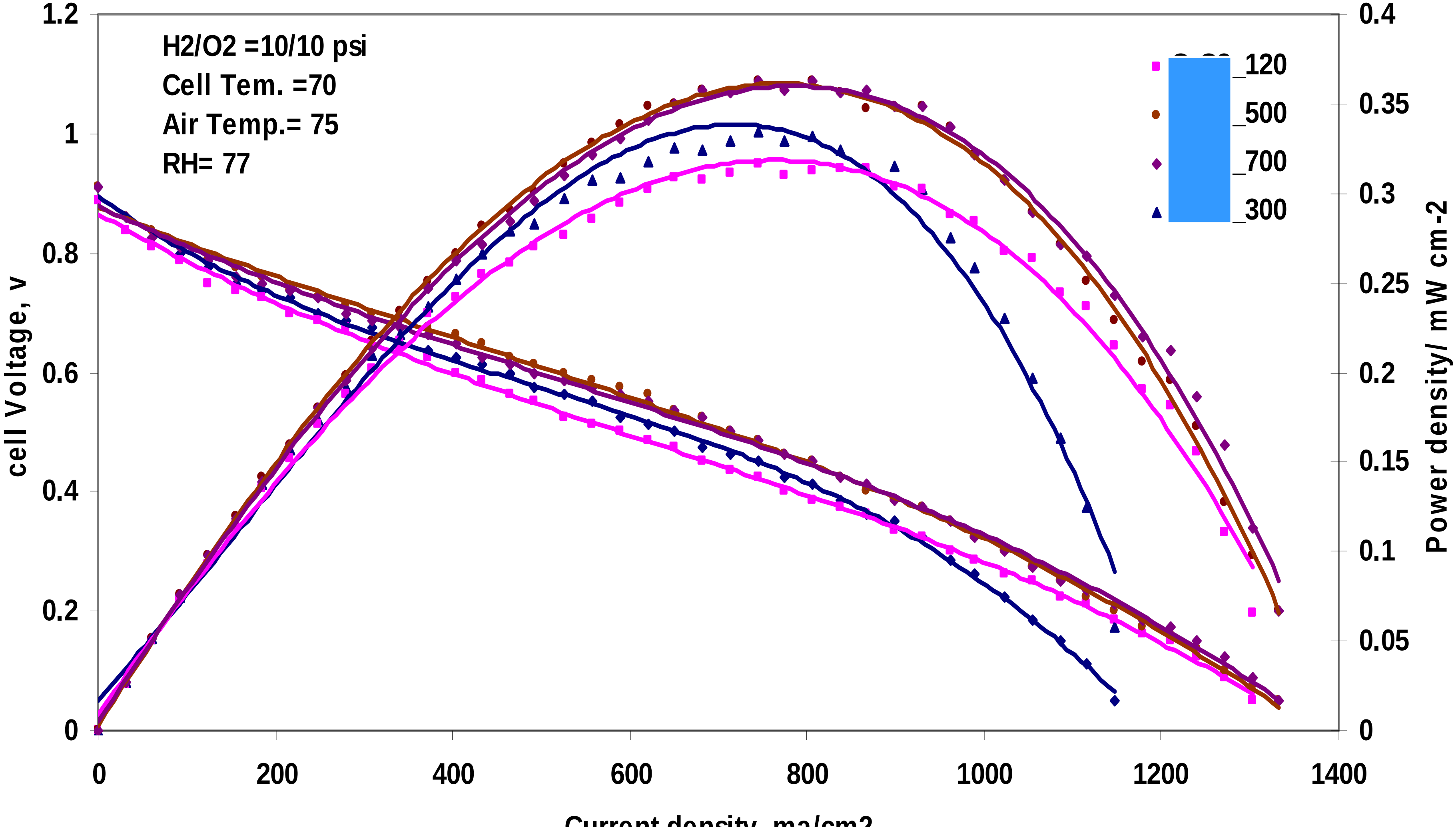
Polarization and Power Curves for Carbide based coating at Various Operation Hours – Max percentage difference -0.33



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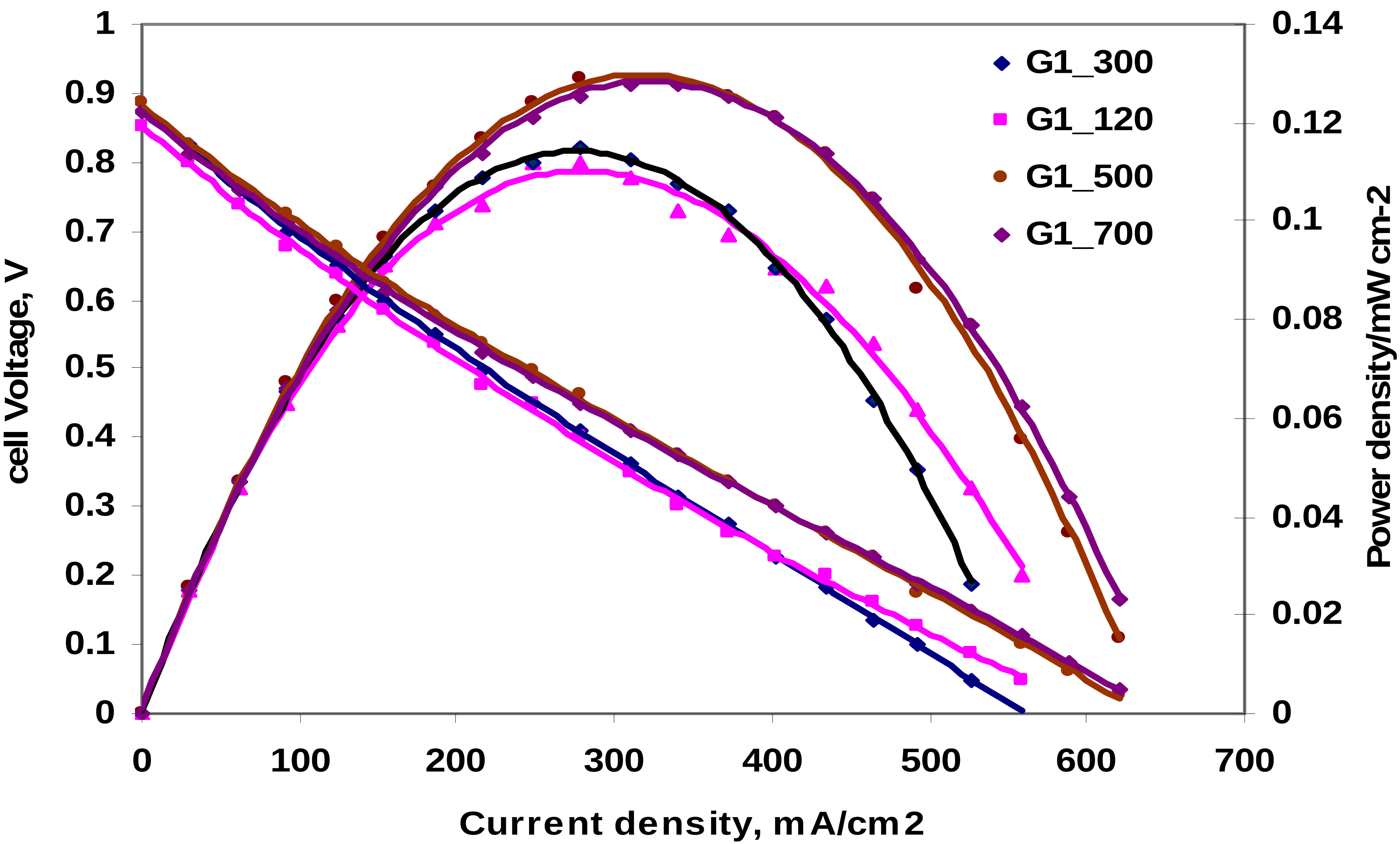
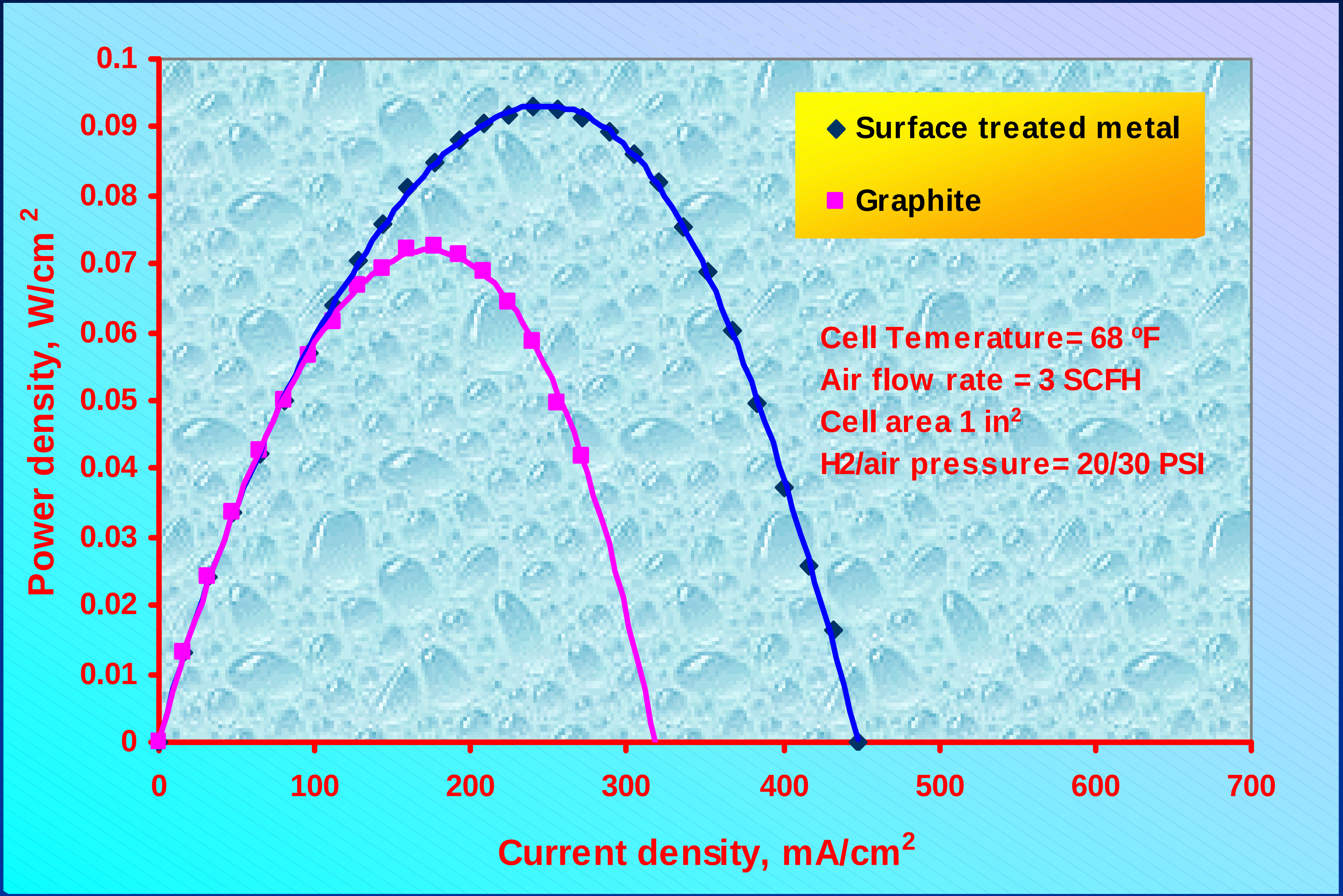
Polarization and Power Curves for graphite Composite Bipolar Plates at Various Operation Hours – Max percentage difference -0.49



Power Density Curve For Comparison Between Aluminum Coated and Graphite



Power Density & Efficiency Curve For Comparison Between Aluminum Coated and Graphite Bipolar Plates

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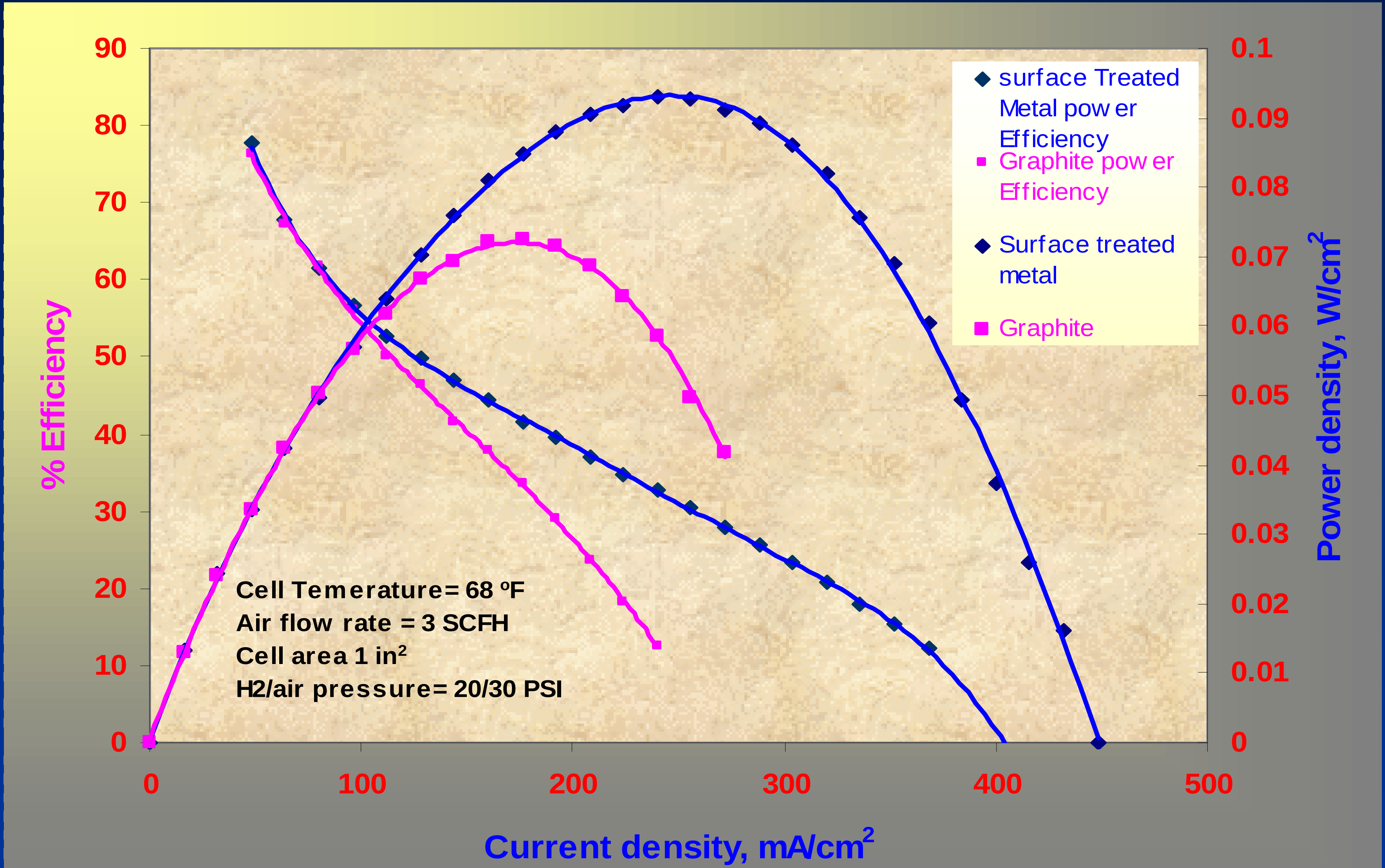

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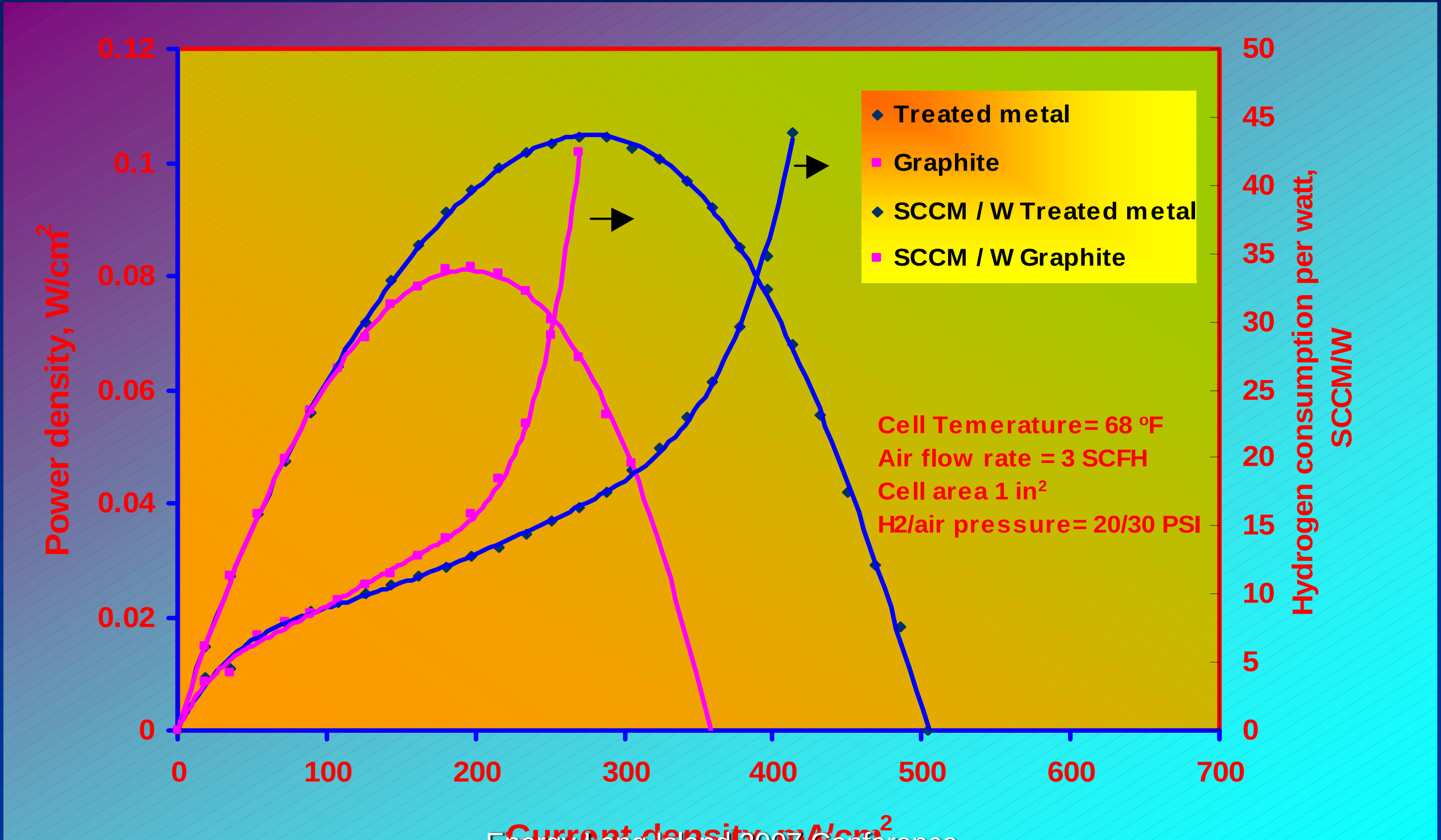
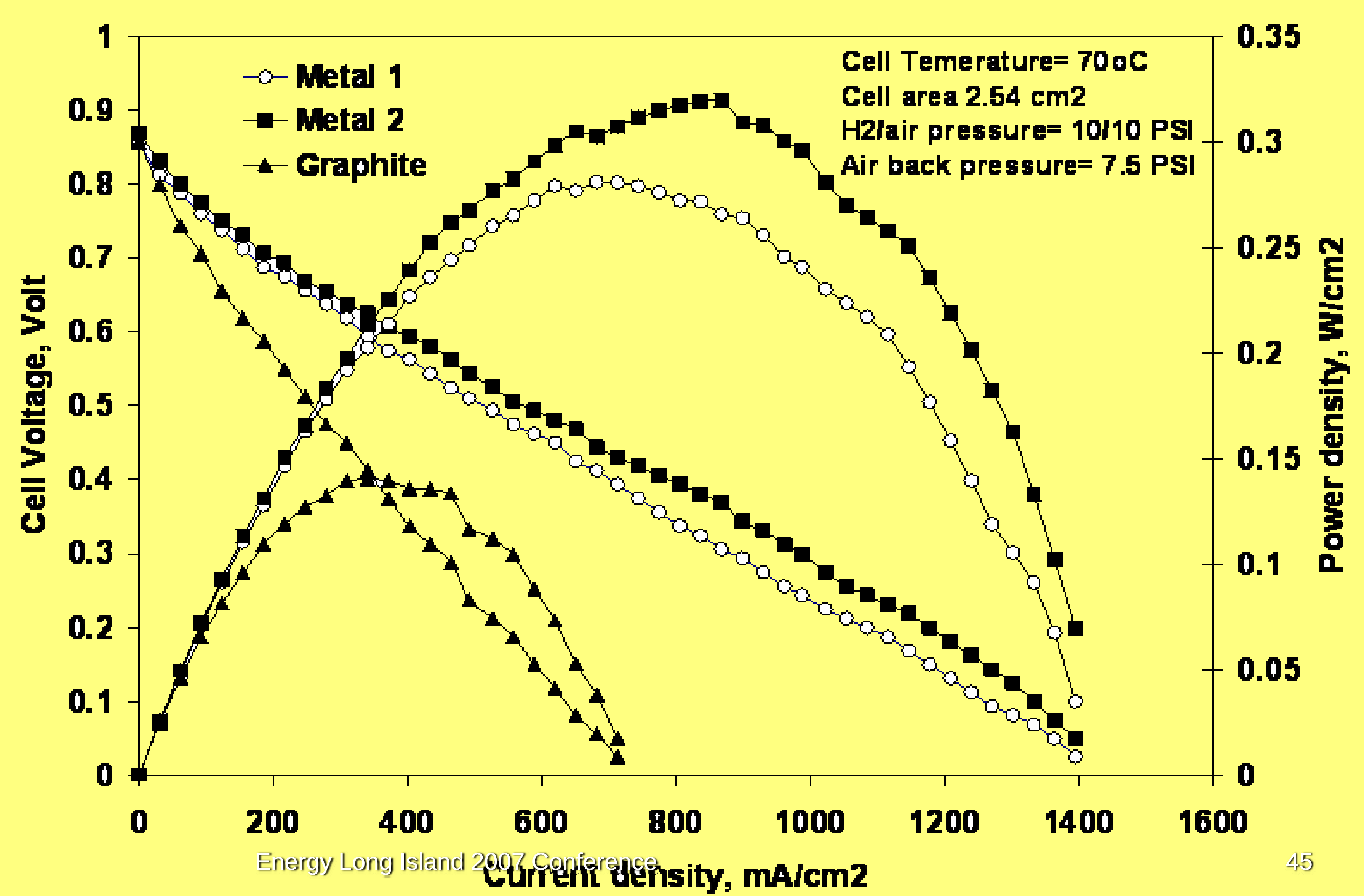
Economics of Metal Vs. Graphite

- **Relative savings in hydrogen Consumption and efficiency improvement by at least 12% due to higher electric and thermal conductivity of Aluminum vs. graphite bipolar plates at 20º C.**



Polarization and Power Curves - After 30 hours of operation at 70º C For Comparison Between Aluminum Coated and Graphite Bipolar Plates



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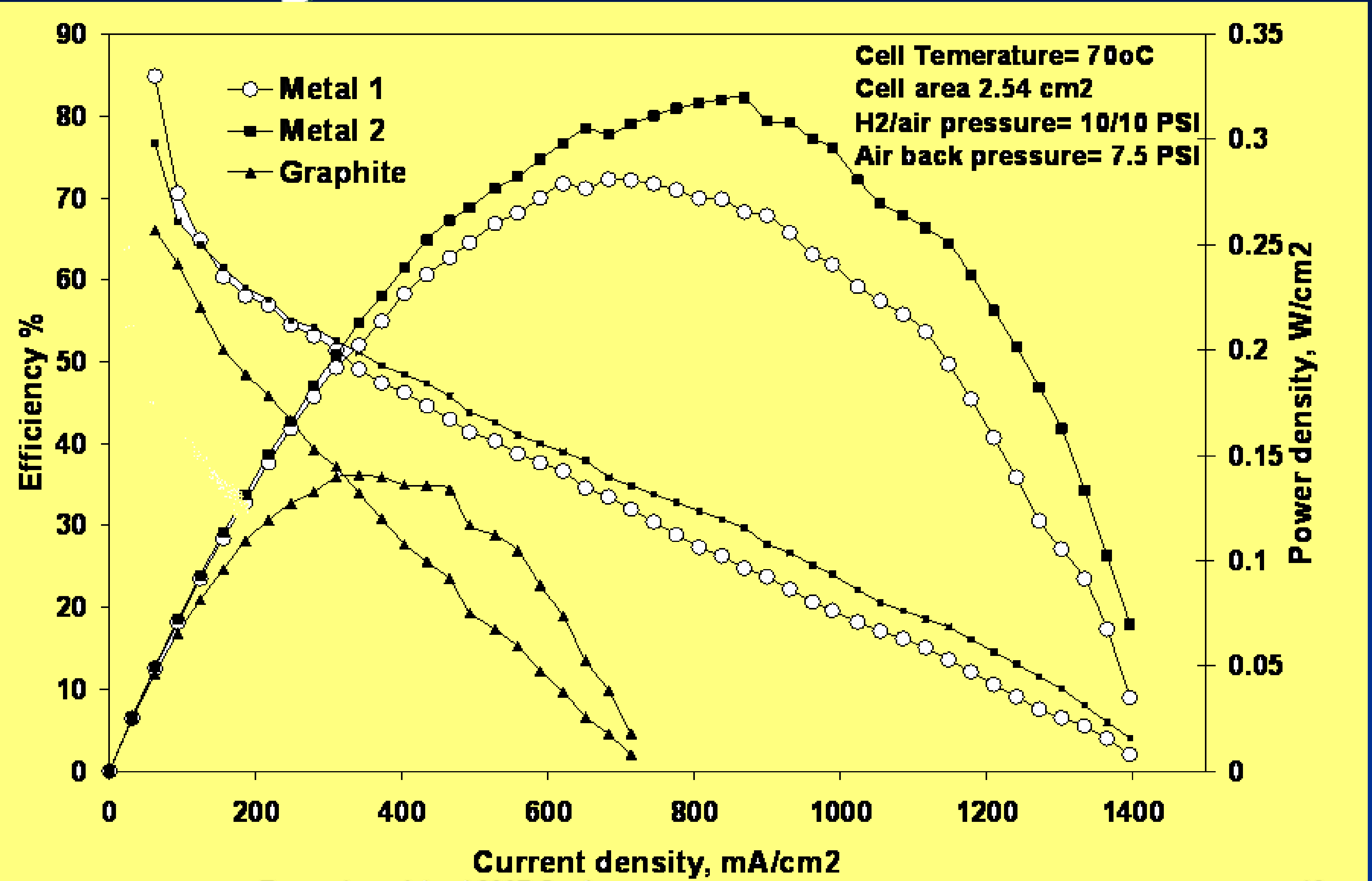
Efficiency and Power Curves - After 30 hours of operation at 70º C



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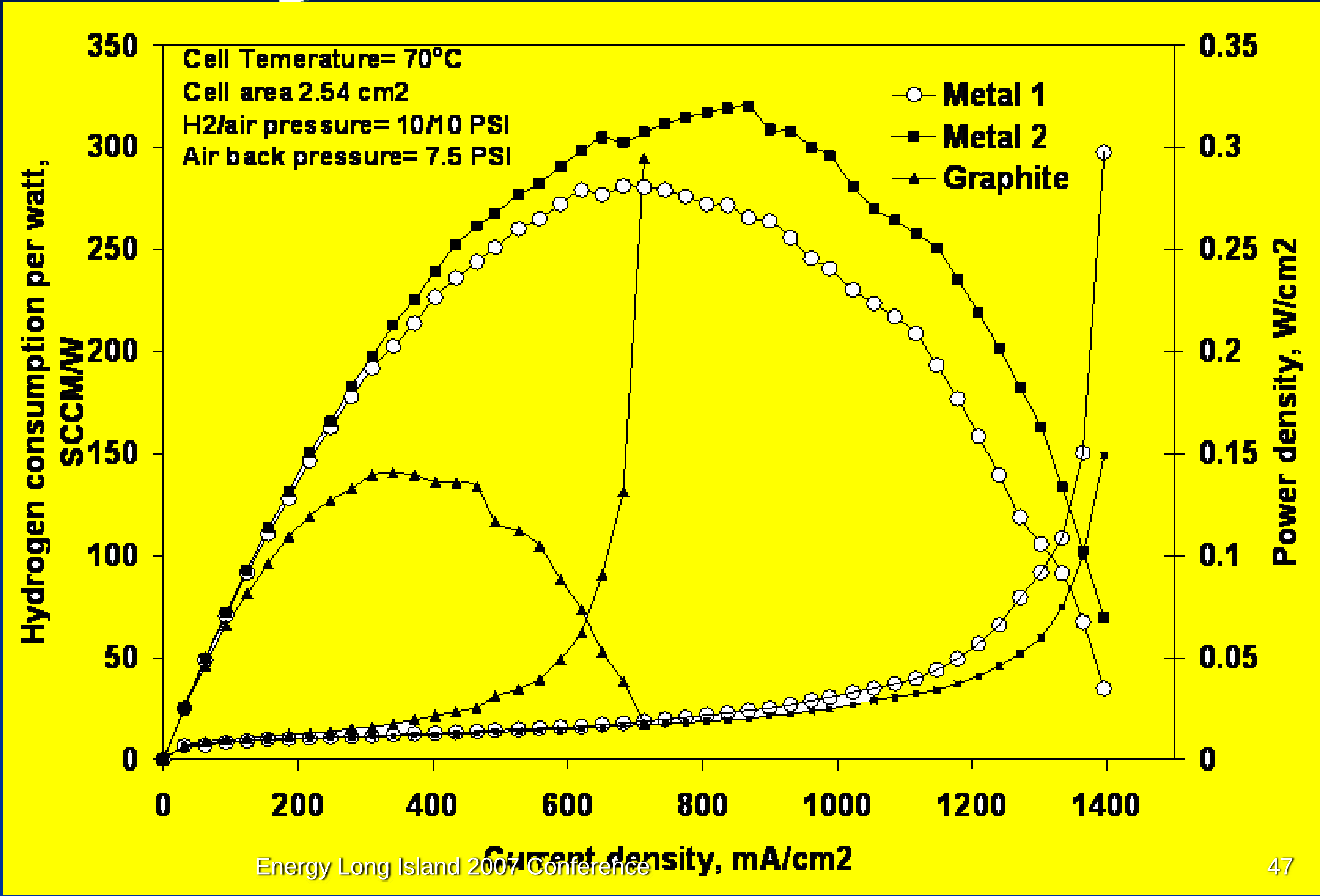
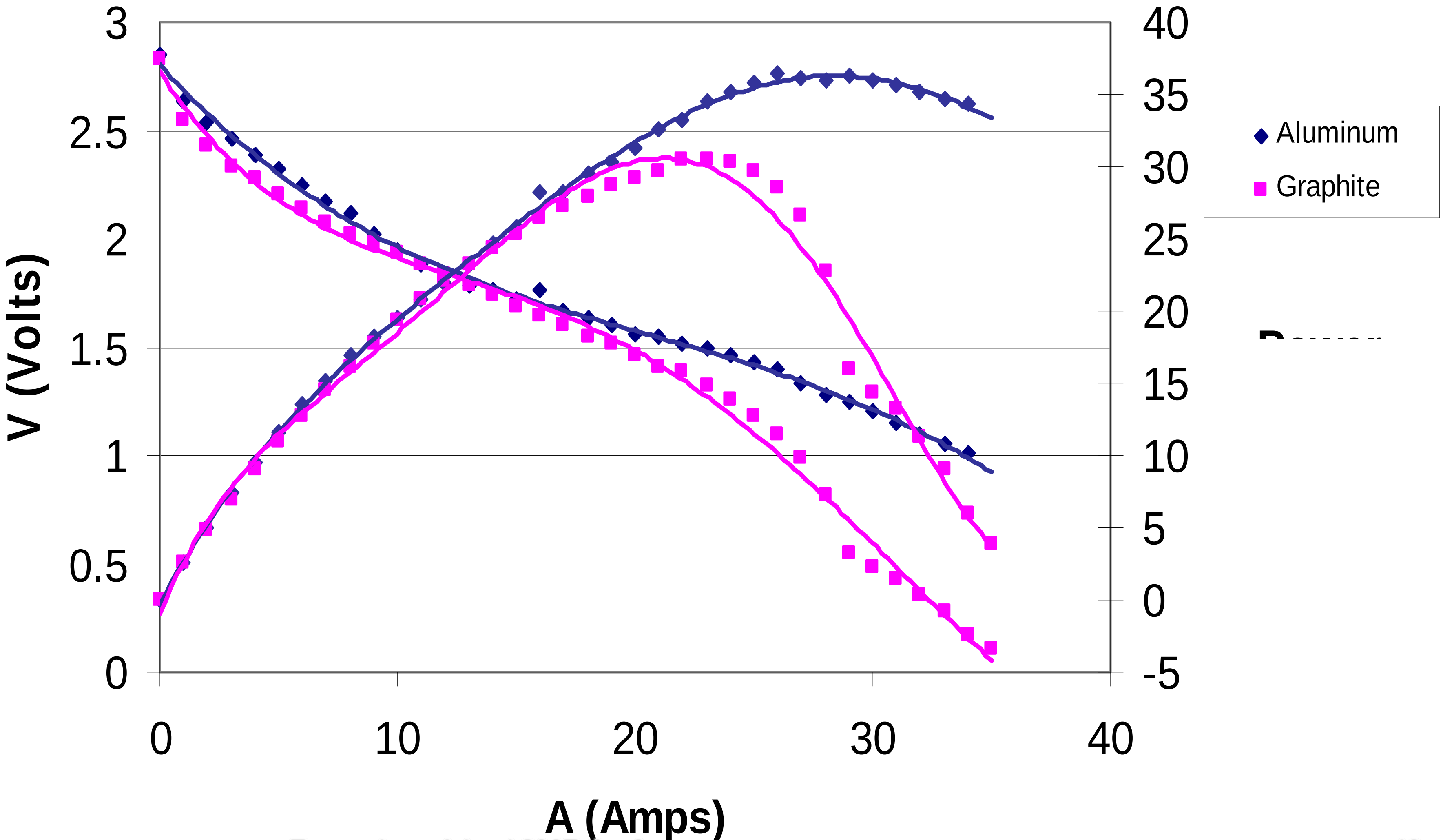
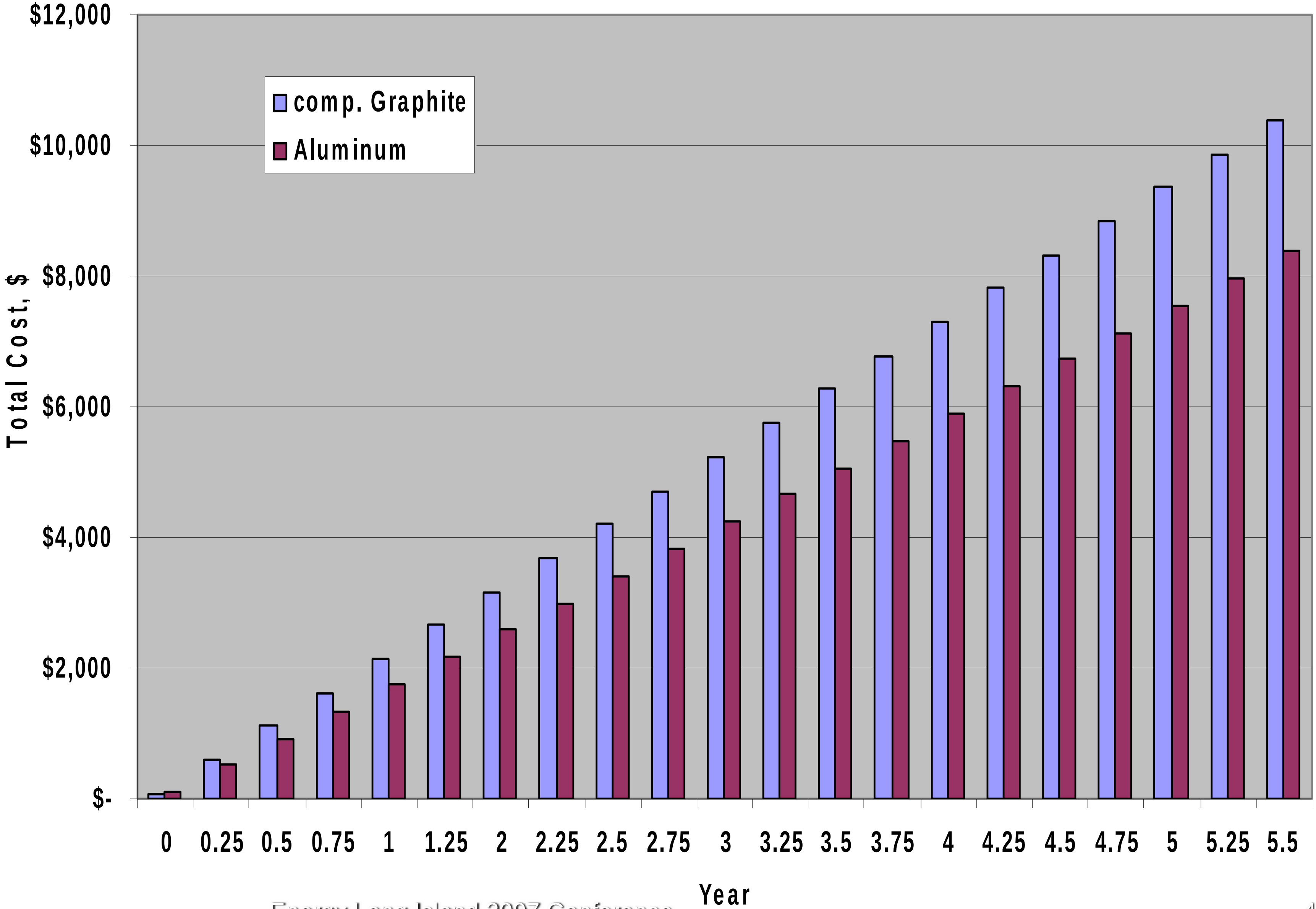
Hydrogen consumption and Power Curves - After 30 hours of operation at 70o C – Hydrogen Consumption Savings of 24%



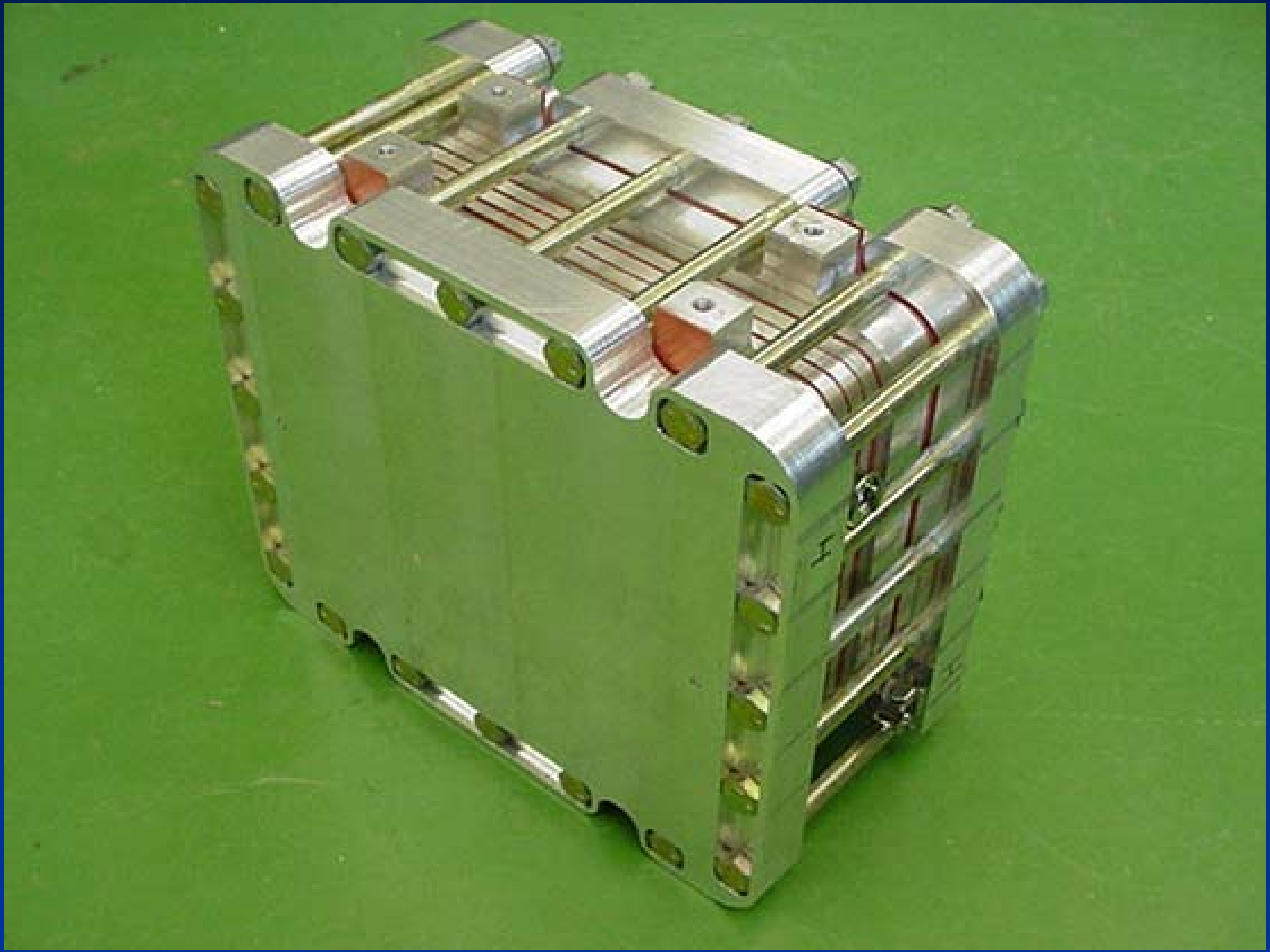
100cm2 Active Area at Room Temp 3 Cells Short Stack



Total Cost Comparison for Power Generated by Aluminum and Graphite Bipolar Plates (Fixed + Running) Costs



Final Stack Design



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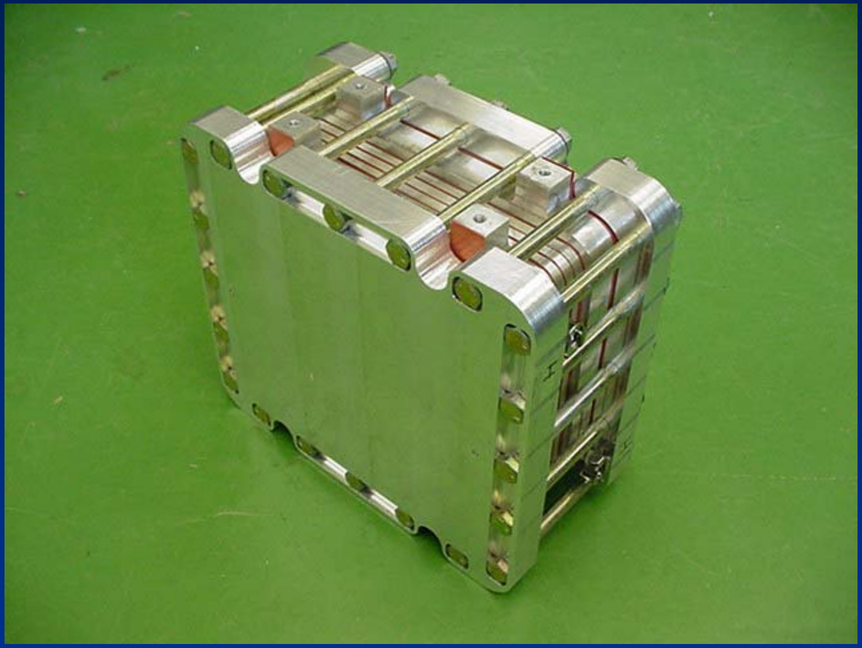
Metallic Vs Graphite bipolar plates



IRTT Current Metallic Bipolar Plates Fuel Cell Power Stack Design using robust, highly conductive and efficient plates with 24% hydrogen consumption savings

Industry Standard Graphite Composites Fuel Cell Power Stack

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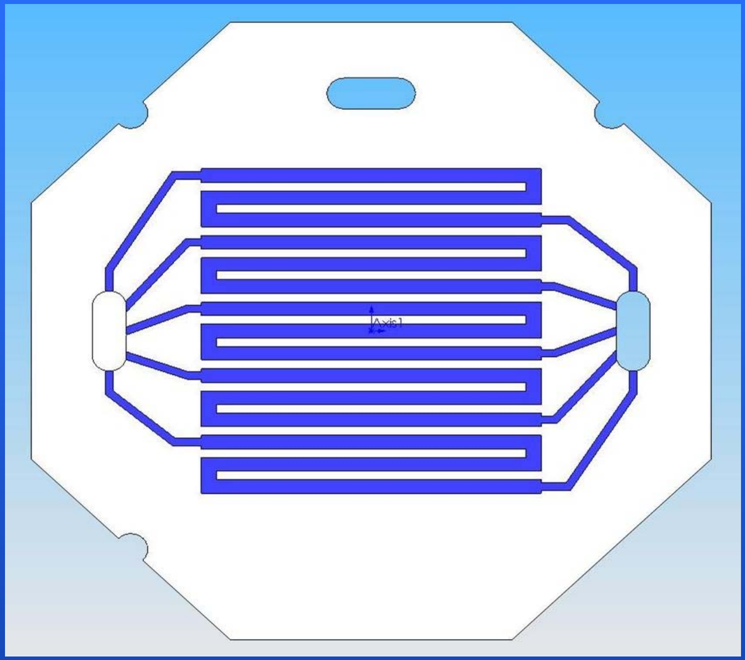
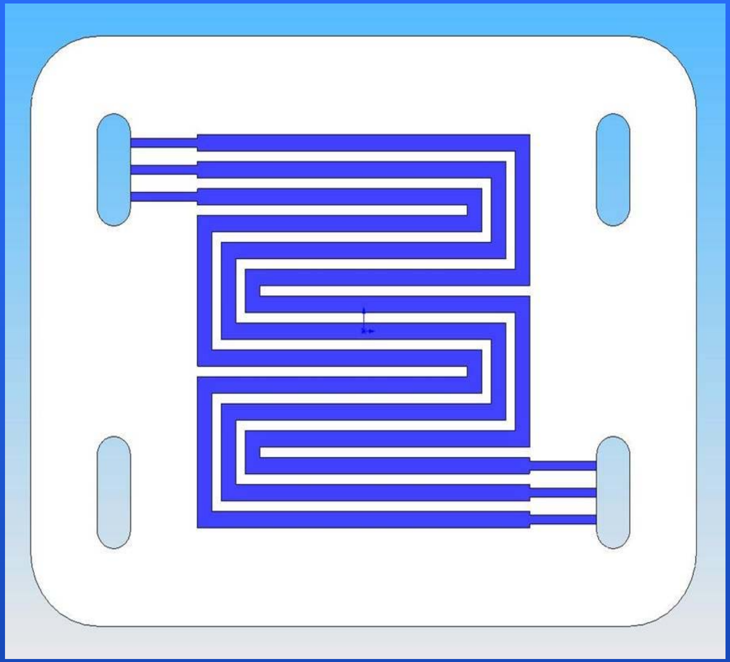
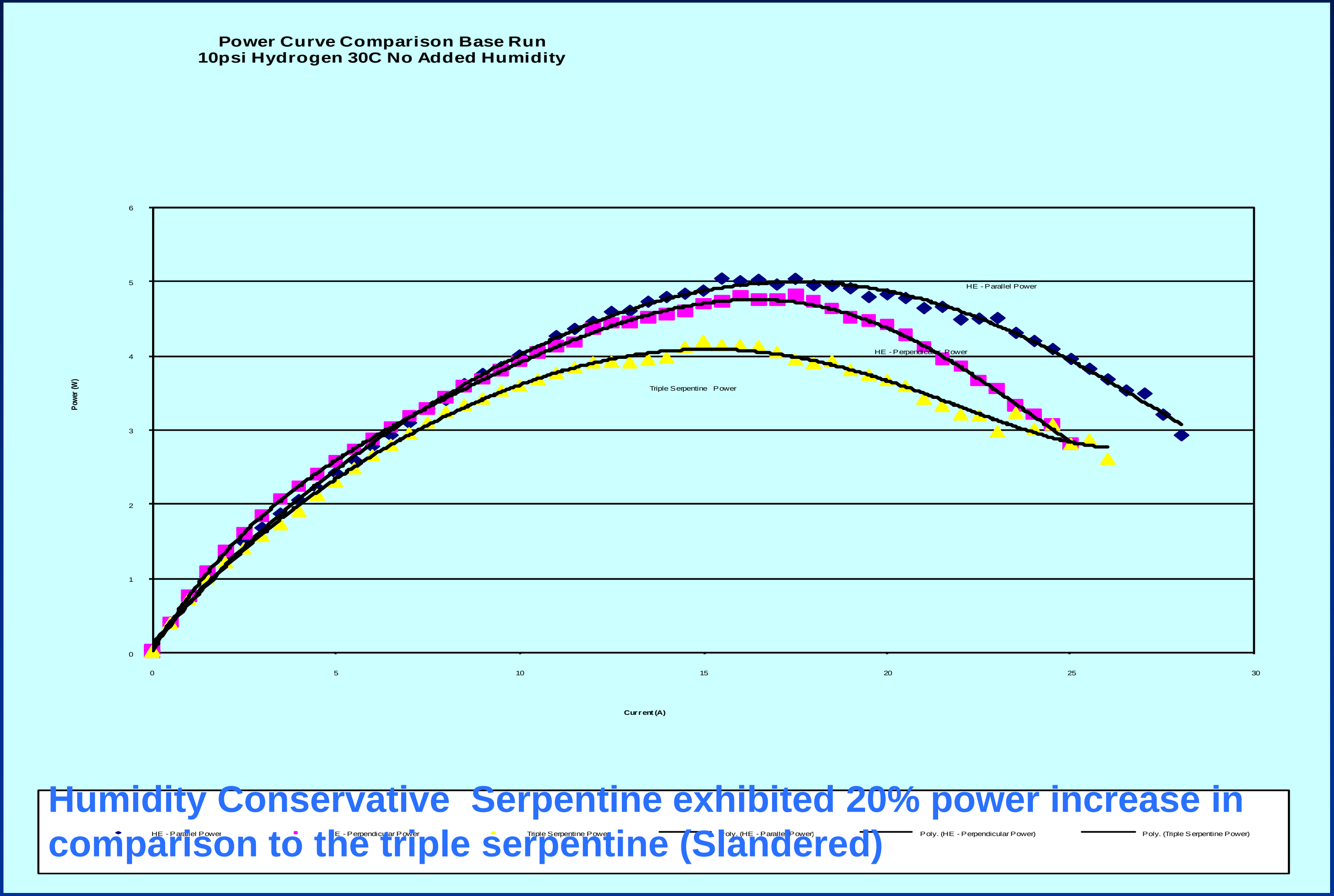


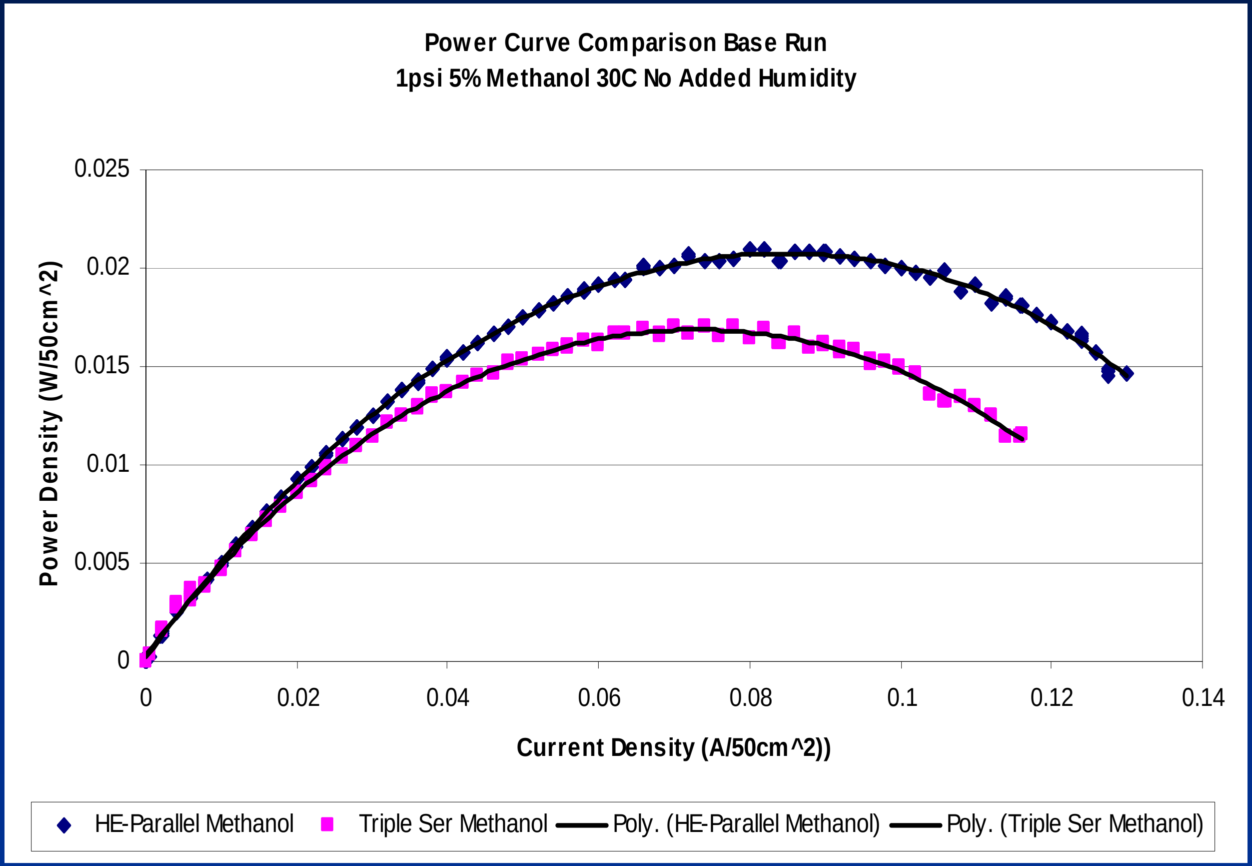
Humidity Conservation Flow Pattern



Triple Serpentine (Standard)



Humidity Conservative Serpentine exhibited 20% power increase in comparison to the triple serpentine (Slandered)



Humidity conservative serpentine exhibited 20% better performance than the standard triple serpentine

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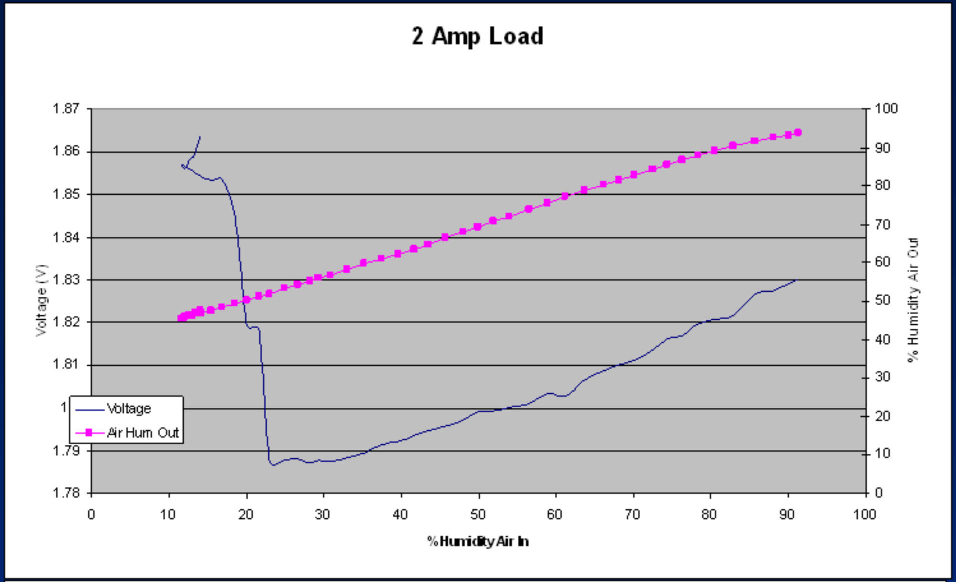
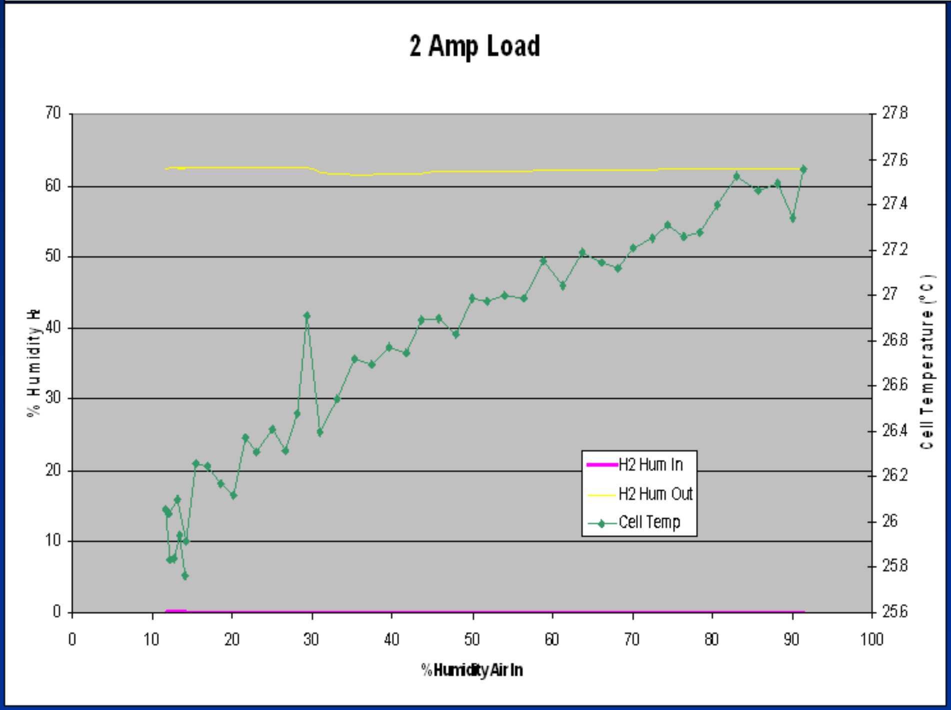
Effect of inlet Air humidity on performance

Humidity at lower temperature could cause flooding and reduction in power

As the temperature continues to increase the humidity dissipates and the cell tends to recover as the Figures in the side exhibits.





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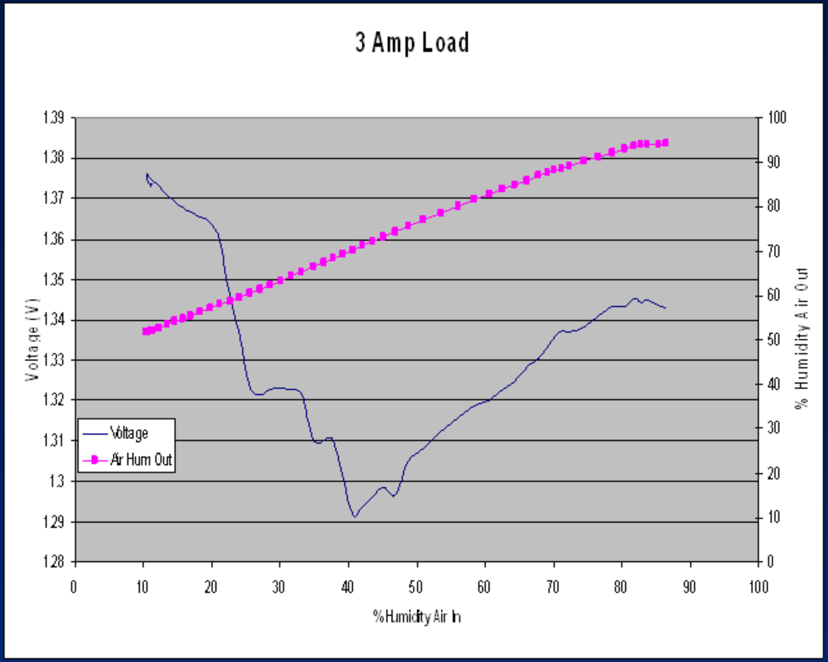

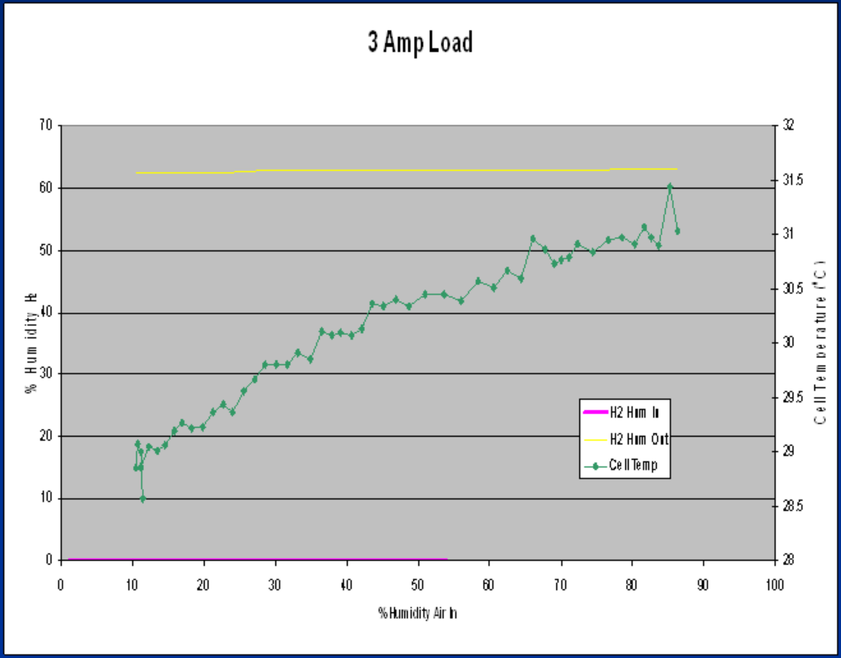

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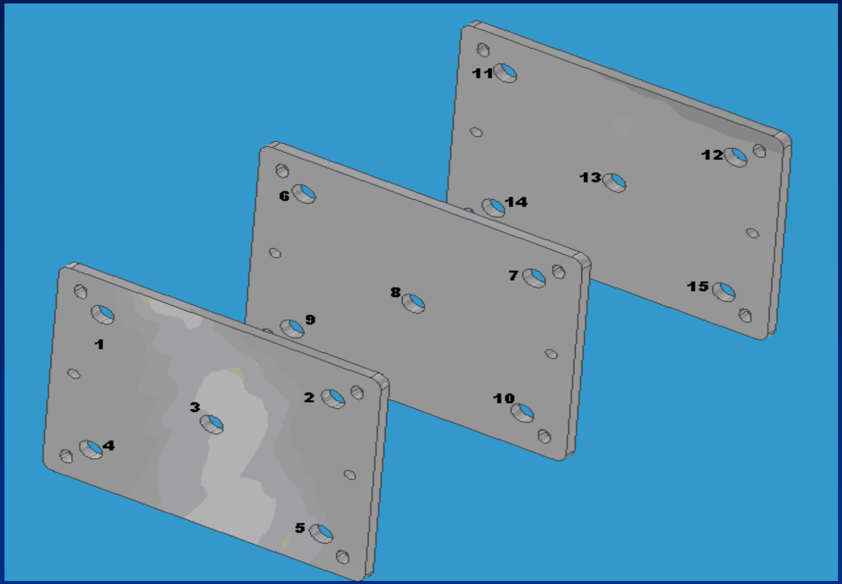
Three instrumented plates with 5 thermocouples per plate as shown in the side figure. The plates are placed in the beginning, middle and end of the stack to measure the internal temperature of the fuel cell.

The objective is to design a cooling system



Thermocouples instrumented plates

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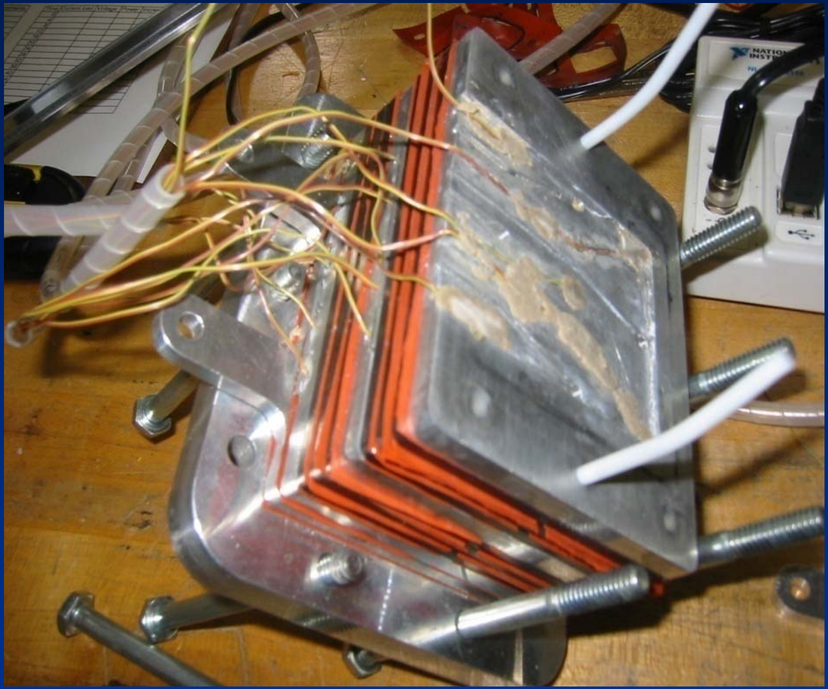

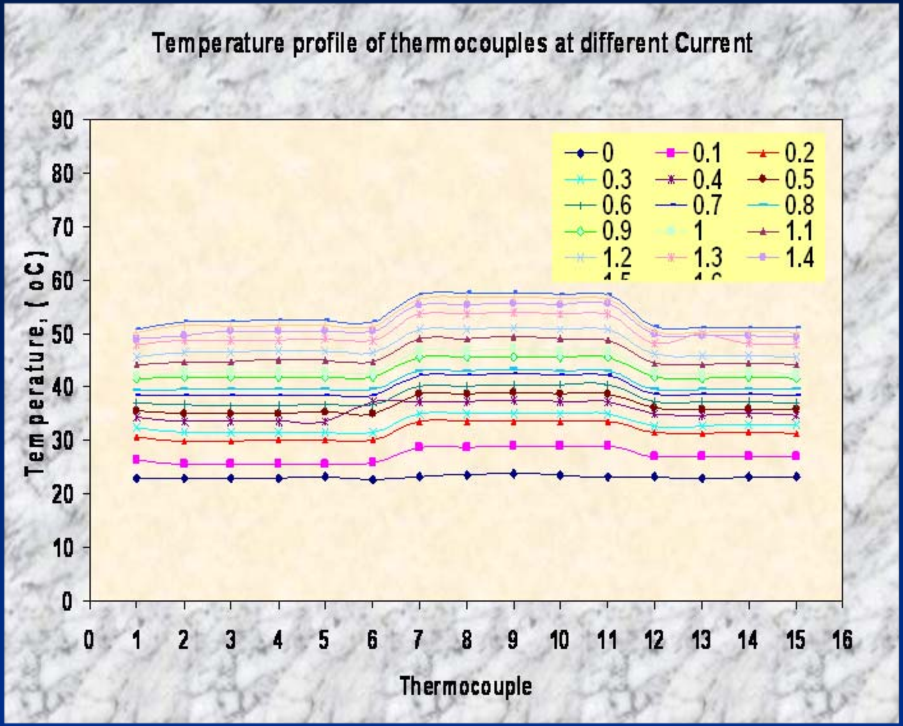

Middle stack plates are subjected to higher temperature than the end plates as the figure above depicts.

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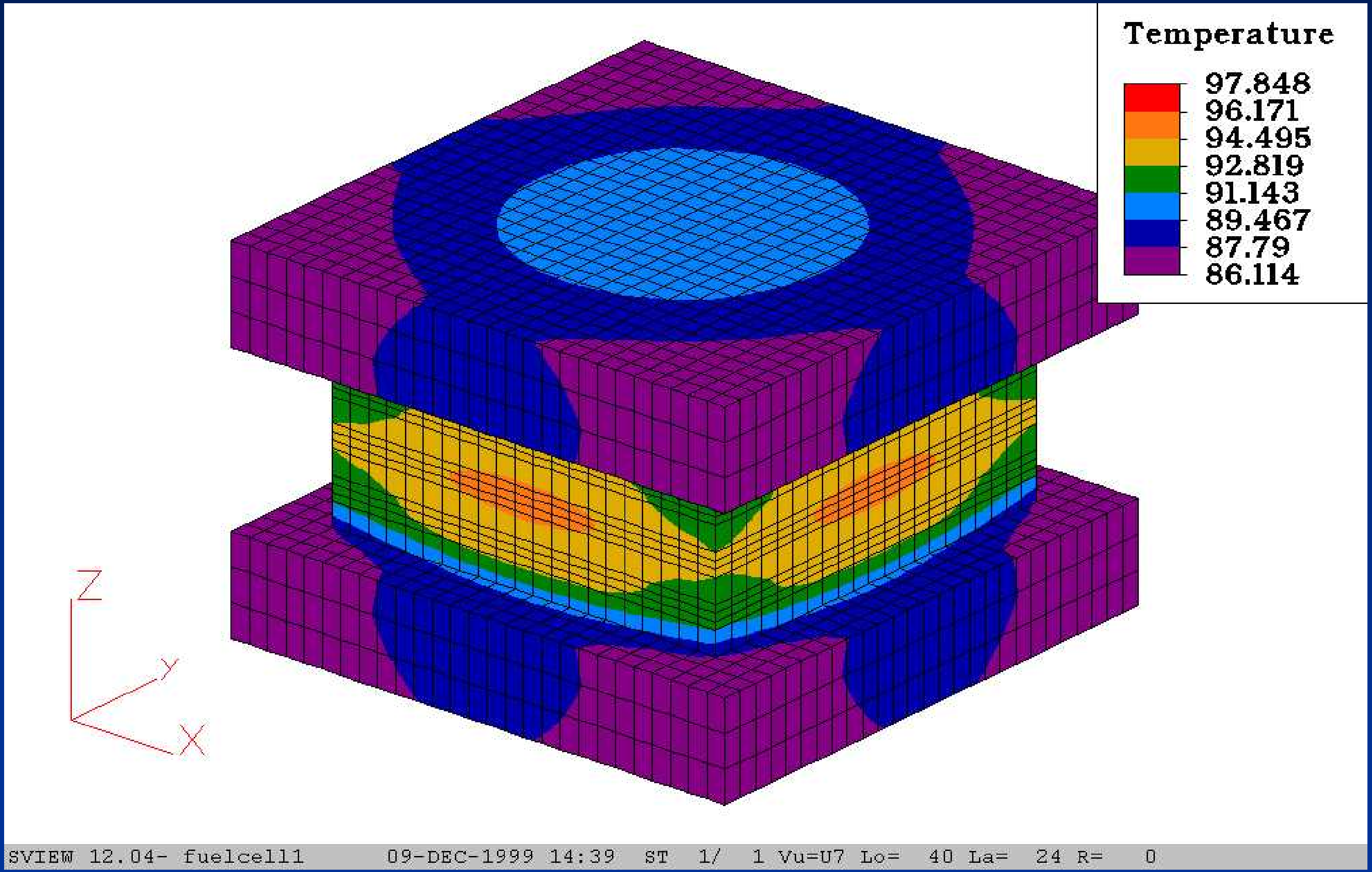
Heat Transfer in Fuel Cell



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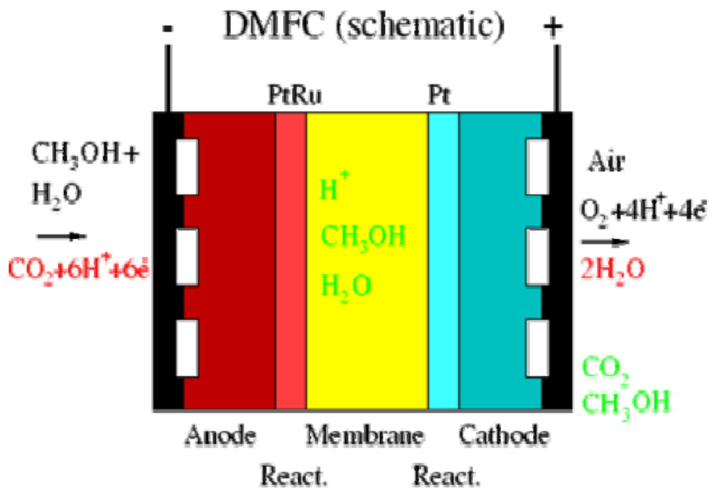
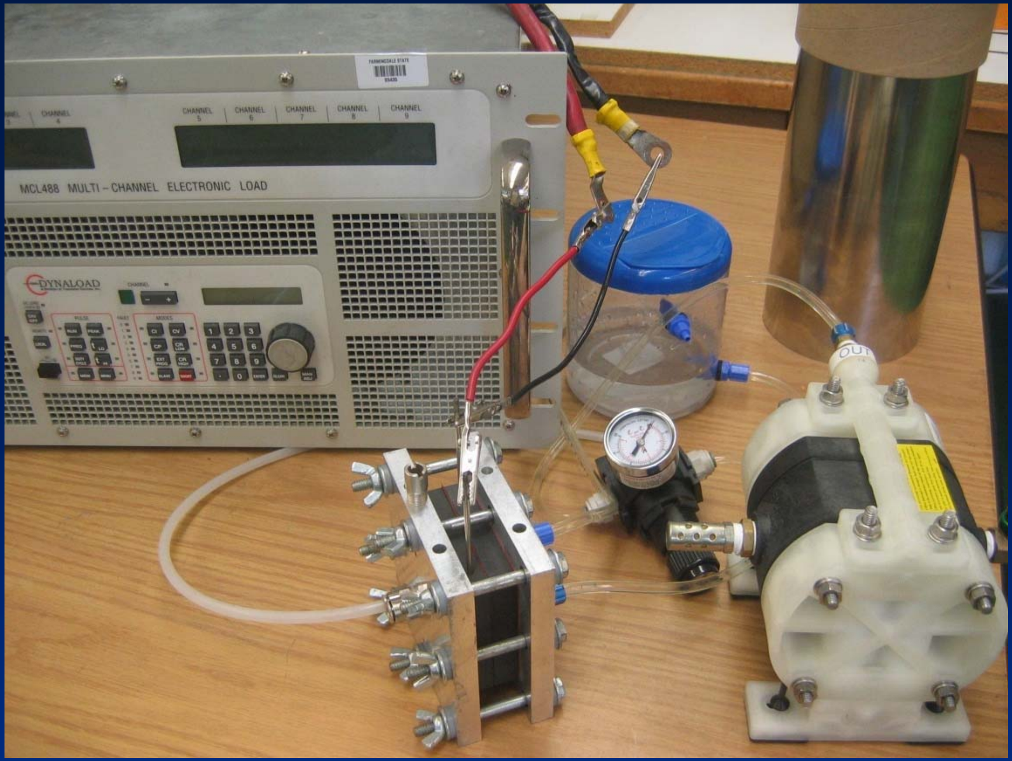


Figure - 1 Schematic of the Direct Methanol Fuel Cell



Direct Oxidation Methanol Fuel Cell Setup

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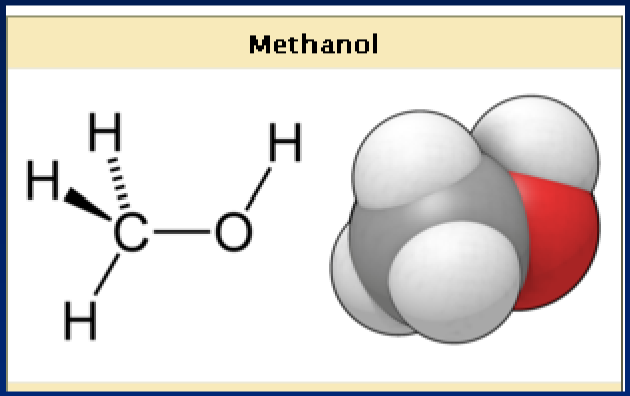
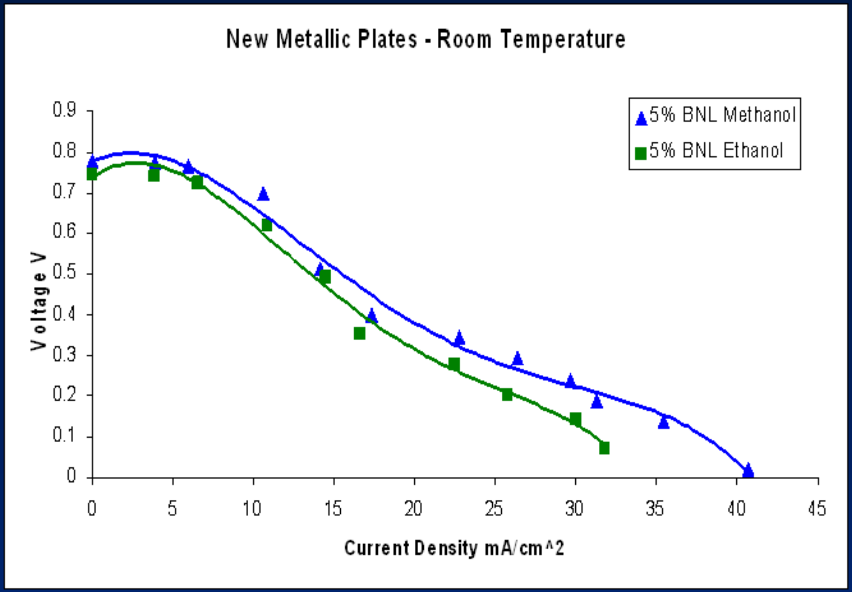
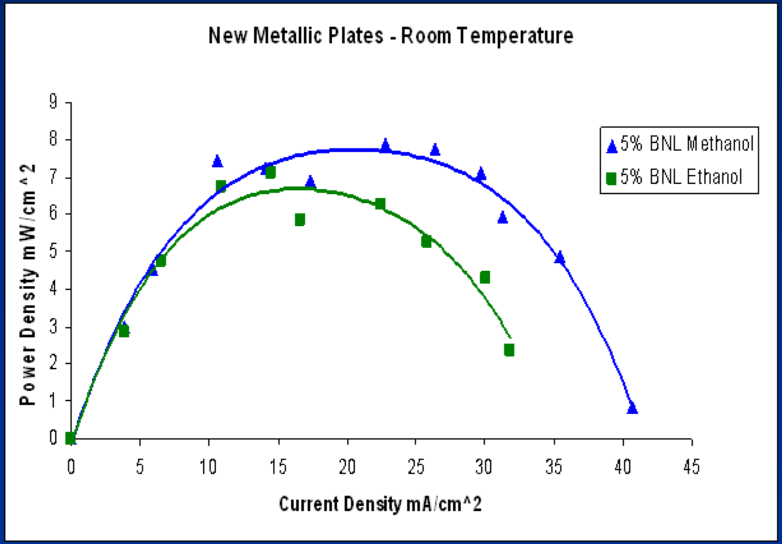
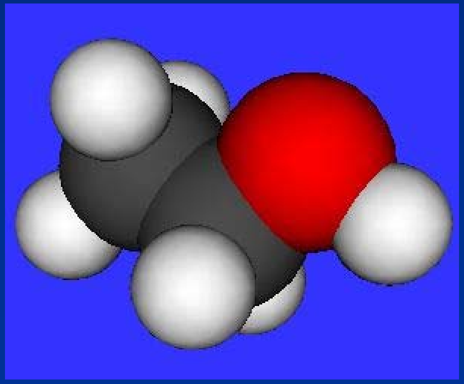




CH_3OH Methanol





Effect of fuel type on cell performance

CH_3CH_2OH Ethanol

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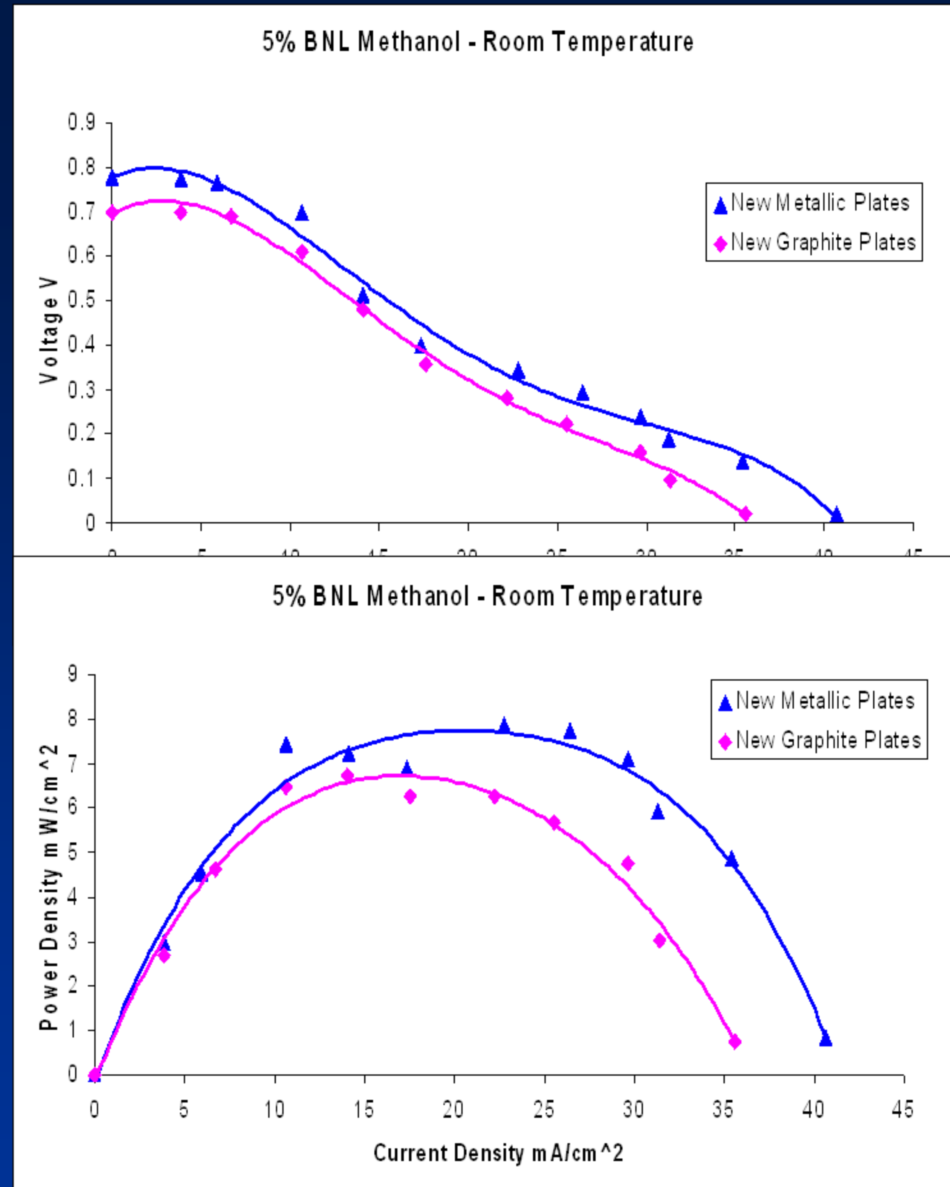
20% Improvement in Performance



Comparison between graphite and Metallic bipolar plate on the performance of fuel cell

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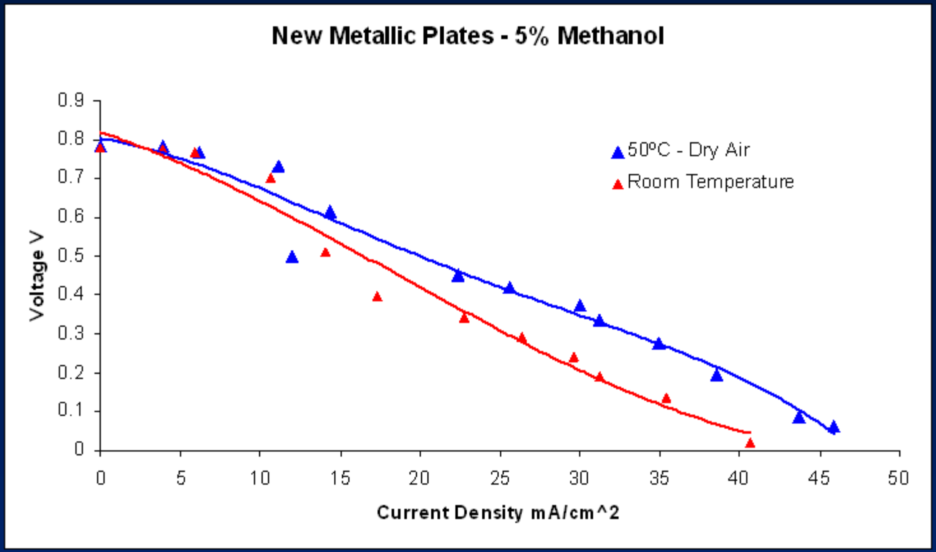
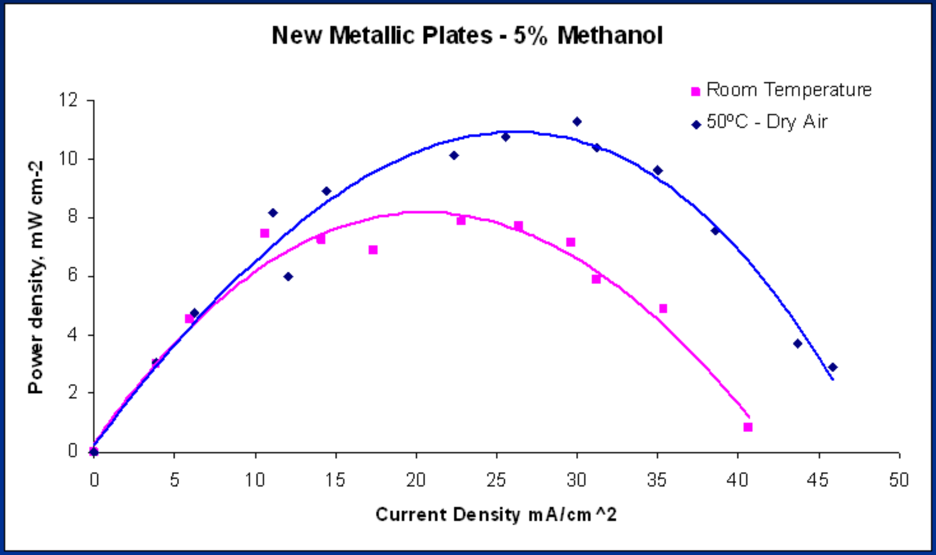
Temperature enhances performance and reaction kinetics





Effect of cell temperature on the performance of fuel cell

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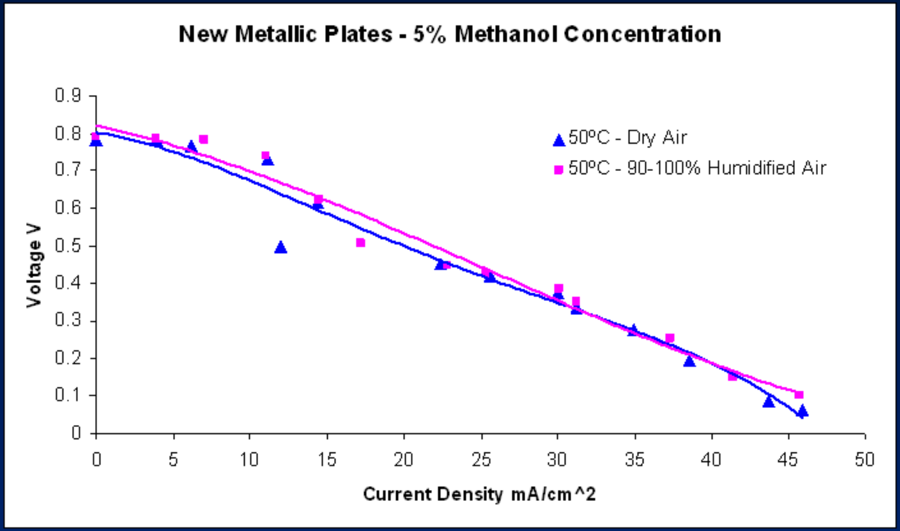

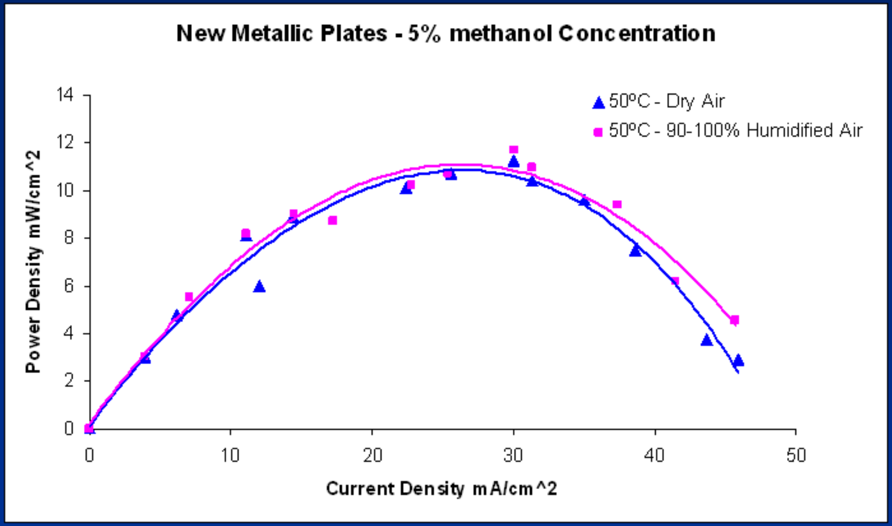

Effect of Dry and Humidified Air on the performance of fuel cell

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Development of Fuel Cell Hybrid Vehicle (FCHV)

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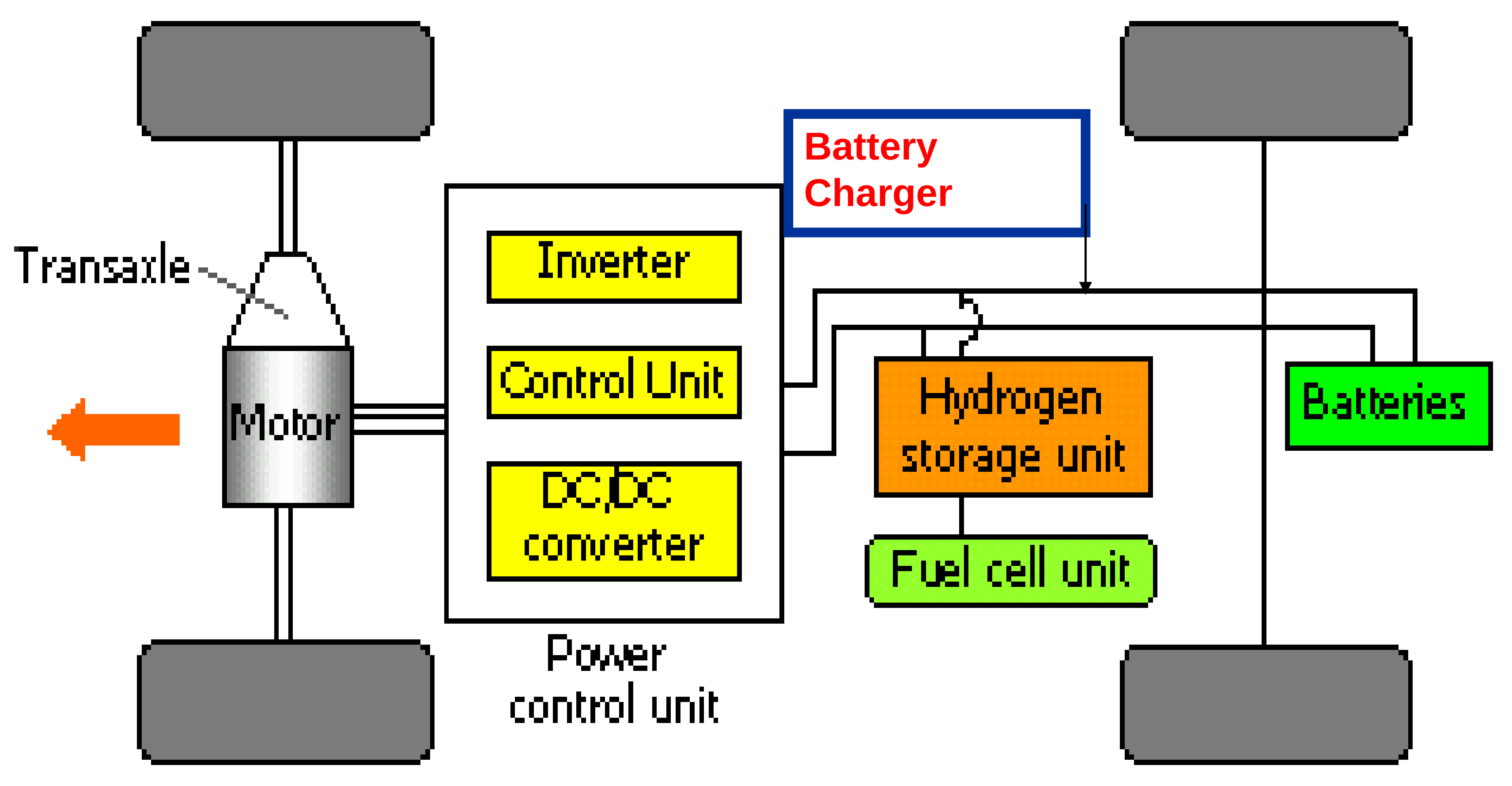
-
Hybrid Fuel Cell Powered Vehicles

IRTT's Fuel Cell Battery Hybrid Vehicle Layout



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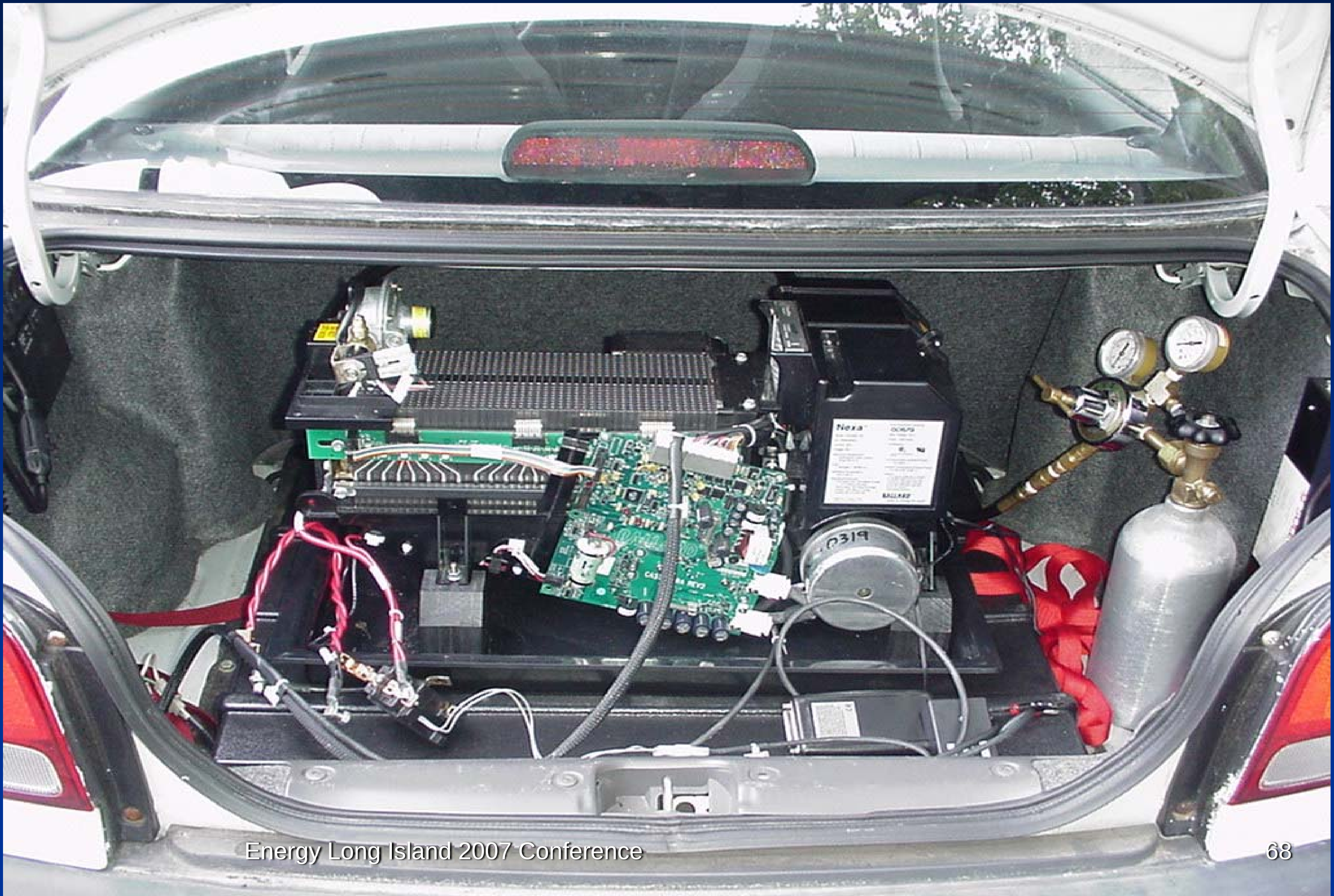
Graphite PEM Fuel Cell (Ballard, Inc.)



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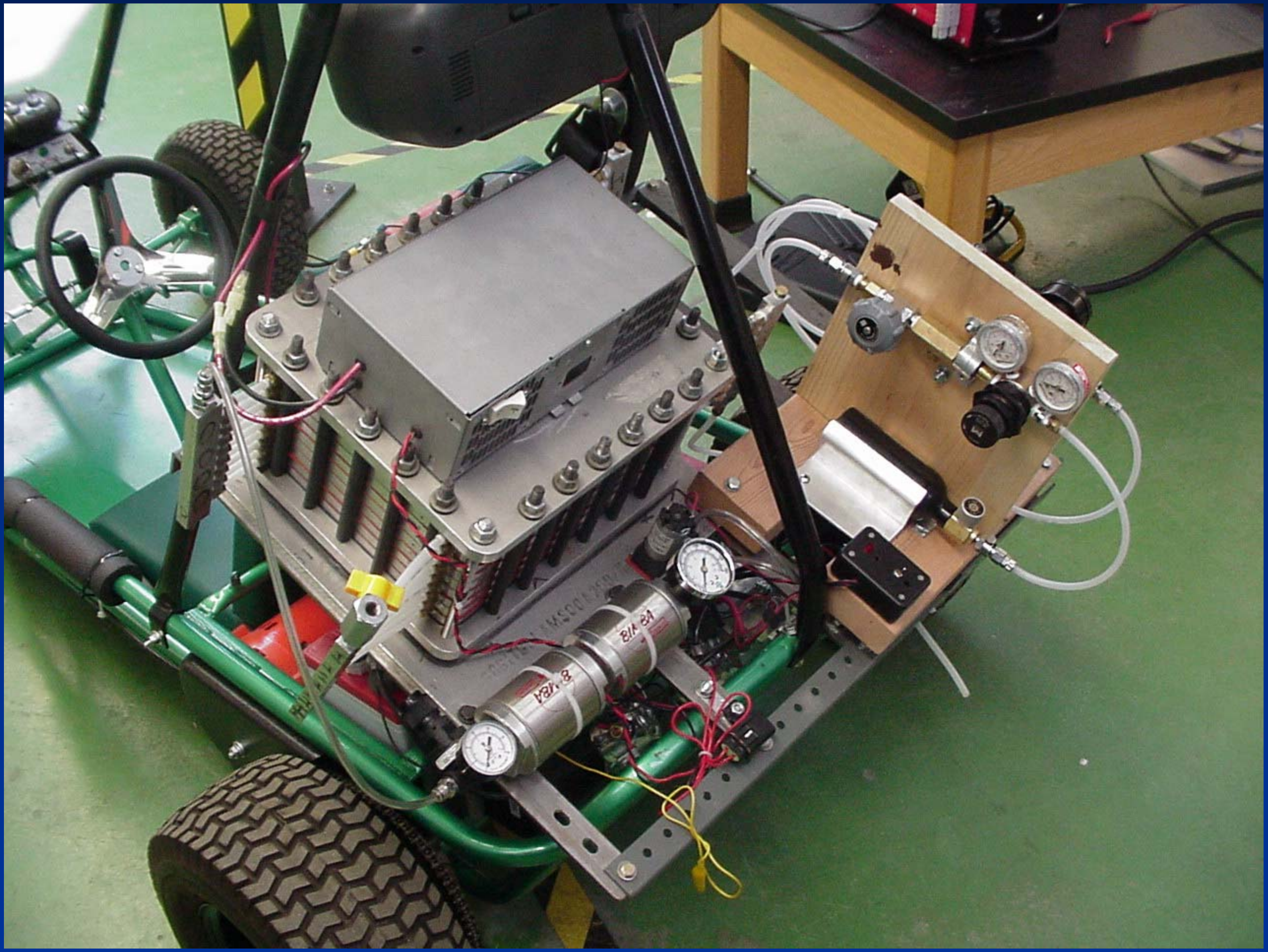
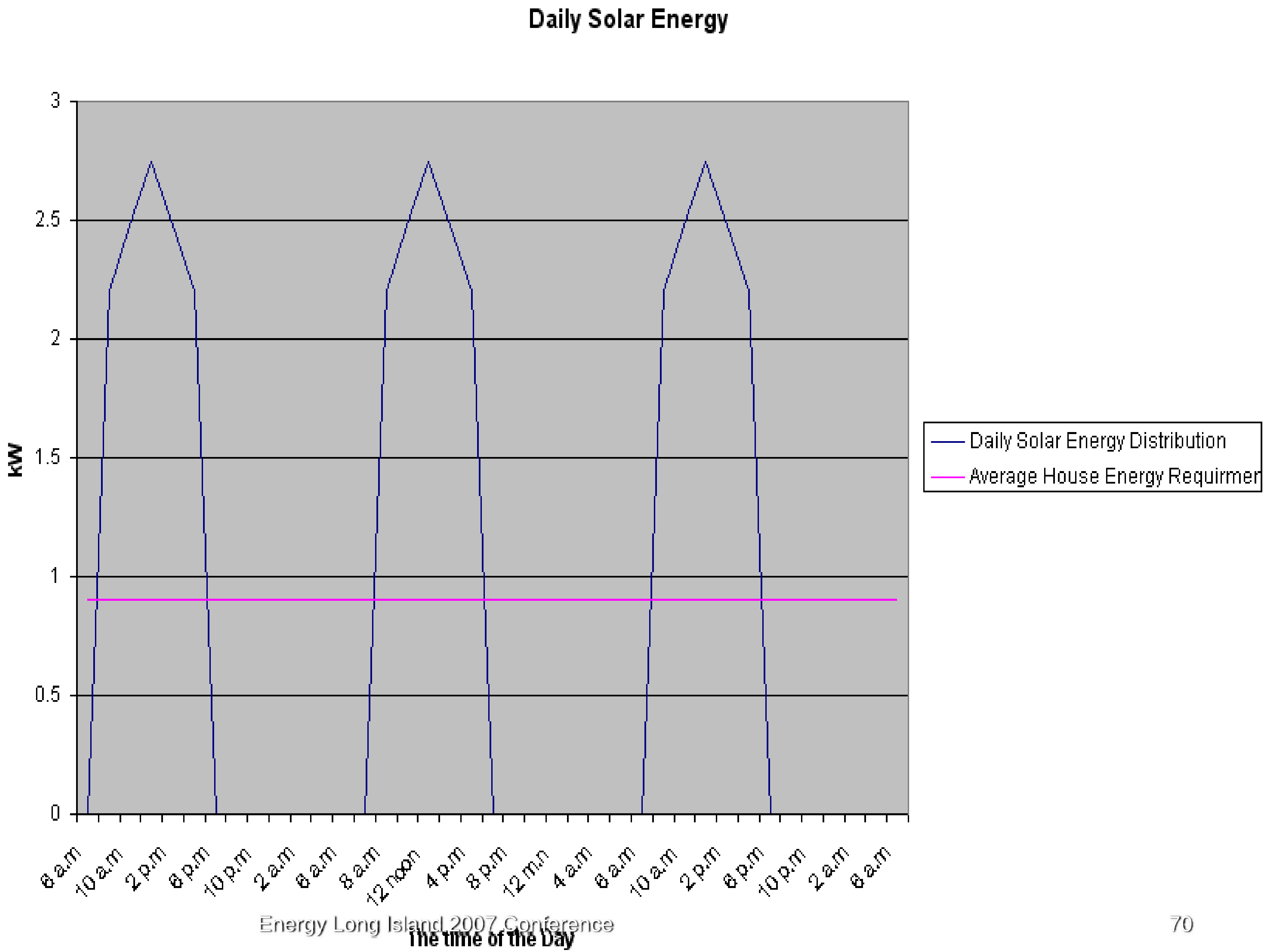
Hybrid Fuel Cell Battery Pack - Powering a Go Cart

- 8 Volts Fuel Cell - 36 Volts Battery - Inverter 8/42 Volts - Battery Charger




Daily Solar Energy
kW
3
2.5
2
1.5
1
0.5
0
6 a.m
10 a.m
2 p.m
6 p.m
10 p.m
2 a.m
6 a.m
8 a.m
12 noon
4 p.m
8 p.m
12 m.n
4 a.m
6 a.m
10 a.m
2 p.m
6 p.m
10 p.m
2 a.m
6 a.m
The time of the Day
Daily Solar Energy Distribution
Average House Energy Requirmen

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Hydrogen and Alternative Energy Project

- Integrated Solar Hydrogen with PEM Fuel Cell System for Powering Residential Homes

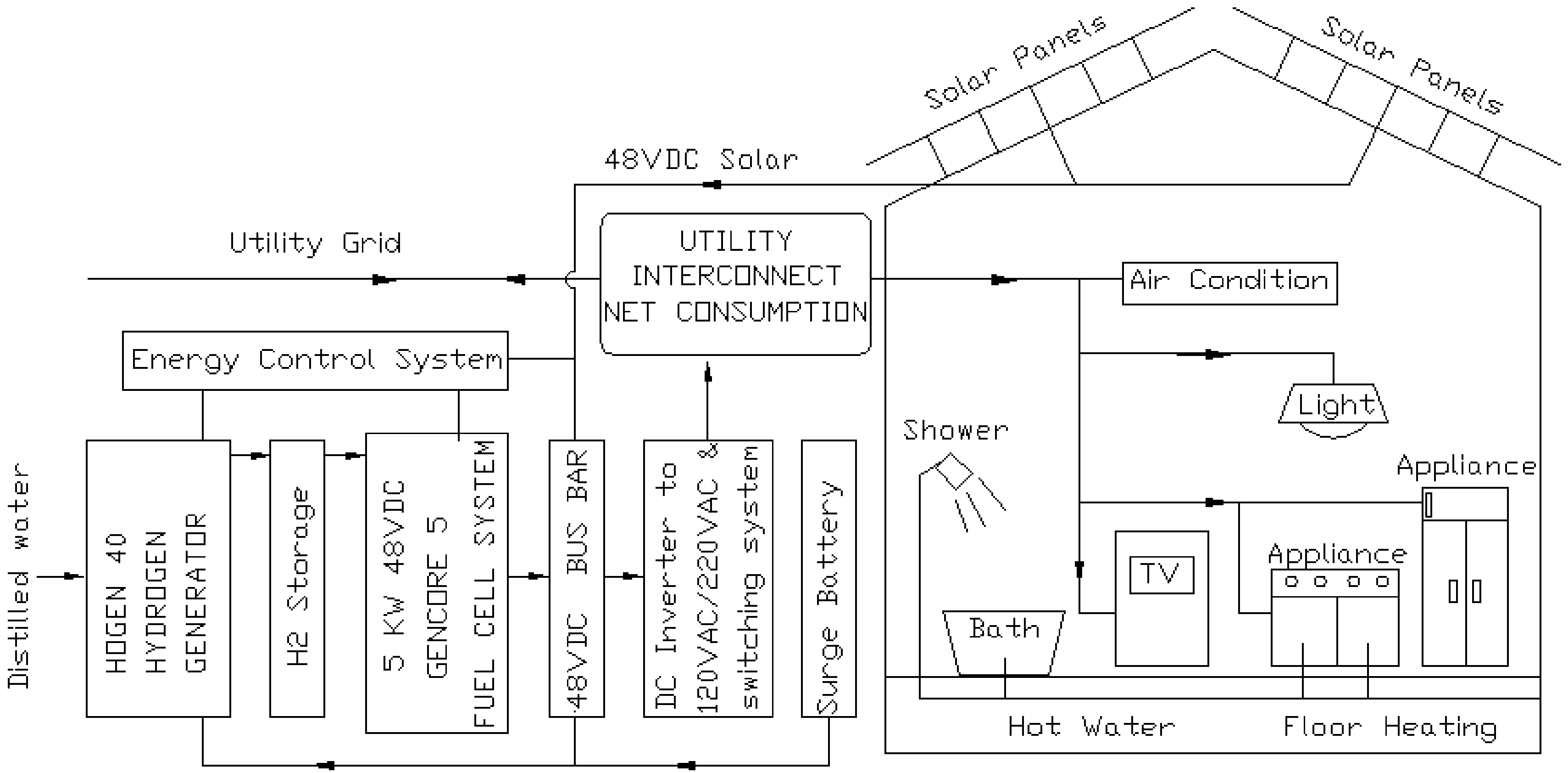

Figure. 1

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Solving the Pollution, Noise and Cost at the truck stops

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Bio Diesel Motorcycle

Farmingdale State College Conclusions

- **IRTT is exited about its new metallic bipolar plates technology and intends to continue this development in cooperation with industry and academia**
- **IRTT has completed the development of Fuel Cell Battery Hybrid Vehicle (FCBHV) with Battery as primary power and Fuel Cell as a secondary**
- **The fuel cell hybrid vehicle and the solar hydrogen powered house have excellent economic potential, environmental advantages and interdisciplinary educational merits for undergraduate and postgraduate students**
- **There is a number of research topics that lend itself for possible collaboration between IRTT and BNL and SBU/AERTC.**

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FUTURE PLAN

- Designing, Manufacturing, and testing of a 5 kW Metallic Bipolar Plates Power Stack Prototype complete with combined air and fluid cooling systems and Balance of Plant.

- Further Development of the Corrosion Resistant coating Quality to Meet the DOE 2010 Target

  and apply this technology to small fue cells for cell phones and labtop computers