HYDROGEN ECONOMY & (PEM) FUEL CELLS

by

Dr. Hazem Tawfik

Director of the Institute for Manufacturing Research
Distinguished Professor Mechanical Engineering Technology

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Agenda

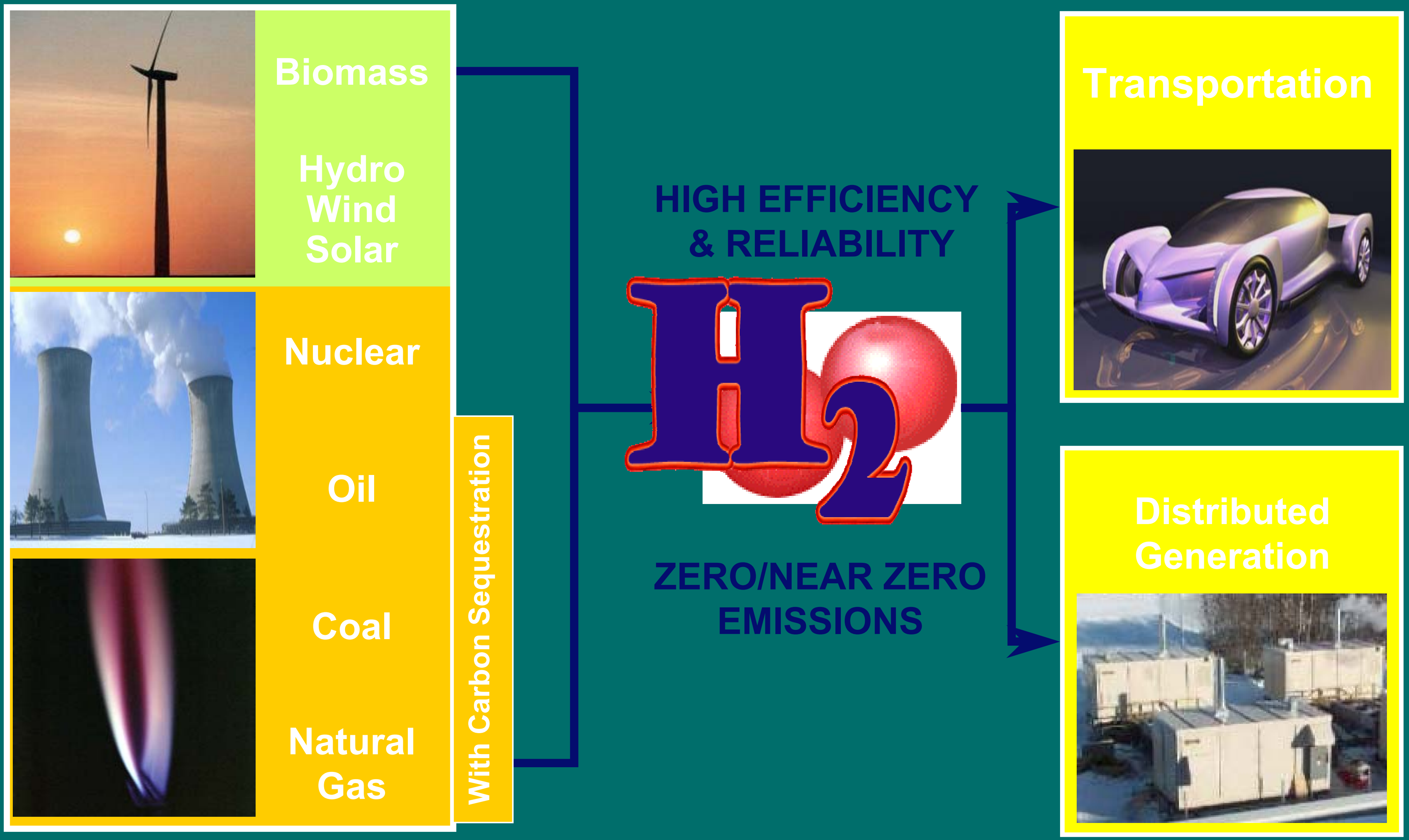
- Why Hydrogen ?
- Hydrogen Economy
- Hydrogen Infrastructure
- Types of Fuel Cells
- Polymer Electrolyte Membrane (PEM)
- IRTT Fuel Cells
- Demonstration

Fuel Energy Density

	Energy Density (MJ/KG.25°C)	Relative Factor Mass Basis	Energy Density (MJ/L.0°C, 1 Atm)	Relative Factor (volume basis)
Hydrogen	141.9	1	0.01274	0.000161
Gasoline	47.27	0.33	35.775	0.45
Natural Gas	47.21	0.33	0.03981	0.0005032
Methane	55.55	0.39	0.03981	0.0005031
Ethanol	22.7	0.16	18.16	0.23
Kerosene	46	0.21	36.8	0.46
Crude Oil	45.55	0.32	38.7175	0.48
Wood	17.12	0.22		
Coal	31.88	0.12	63.76	0.8
Aluminum	29.3	0.206	79.11	1

Why H_2? Why Fuel Cells?

***Why Hydrogen?** It's abundant, clean, efficient, and can be derived from diverse domestic resources.*



President Bush Launches the Hydrogen Fuel Initiative

"Tonight I am proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles.

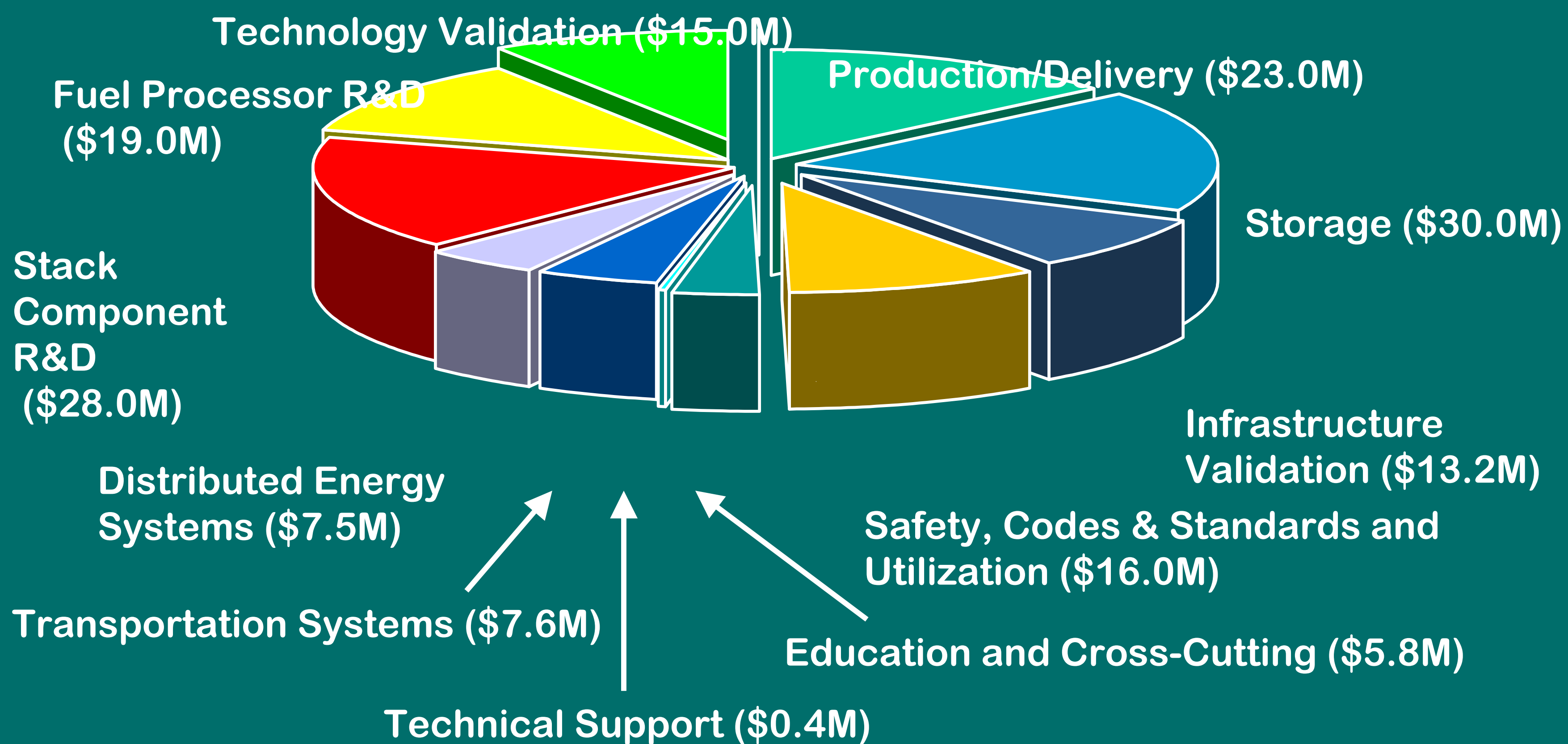
"A simple chemical reaction between hydrogen and oxygen generates energy, which can be used to power a car producing only water, not exhaust fumes.

"With a new national commitment, our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom so that the first car driven by a child born today could be powered by hydrogen, and pollution-free.

"Join me in this important innovation to make our air significantly cleaner, and our country much less dependent on foreign sources of energy."

2003 State of the Union Address
January 28, 2003

2004 Hydrogen and Fuel Cell Budget Request (Key Activities)



Total FY 04 Request $165.5M

Hydrogen Infrastructure and Fuel Cell Technologies put on an Accelerated Schedule

-
    - $1.2 billion for hydrogen and fuel cells RD&D ($720 million in new money)
    - $0.5 billion for hybrid and vehicle technologies RD&D
-

Fuel Cell Vehicles in the Showroom and Hydrogen at Fueling Stations by 2020

President's Hydrogen Fuel Initiative Complements FreedomCAR

- Freedom from foreign petroleum dependence
- Freedom from pollutant and carbon dioxide emissions
- Freedom for Americans to drive where they want, when they want, in the vehicle of their choice
- Freedom to obtain fuel affordably and conveniently

On January 9, 2002, Energy Secretary Abraham announced the FreedomCAR Partnership

FreedomCAR and Fuel Initiative

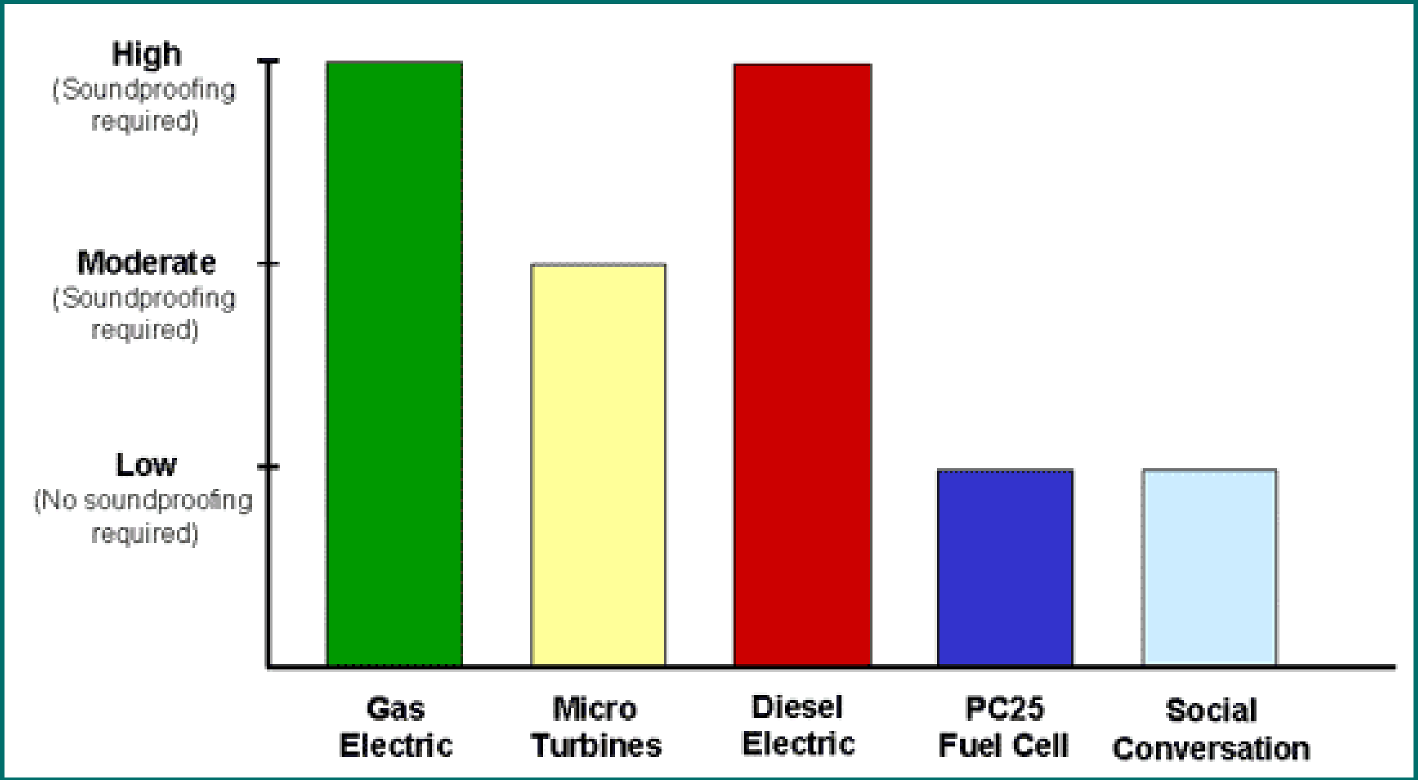
H_2

Advantages of Fuel cells

- Clean Reliable Source of Energy
- High Efficiency
- Hydrogen is available in abundance
- Combined Heat and Power
- Distributed Generation
- Peak Load Shaving
- Low Operating Temperature

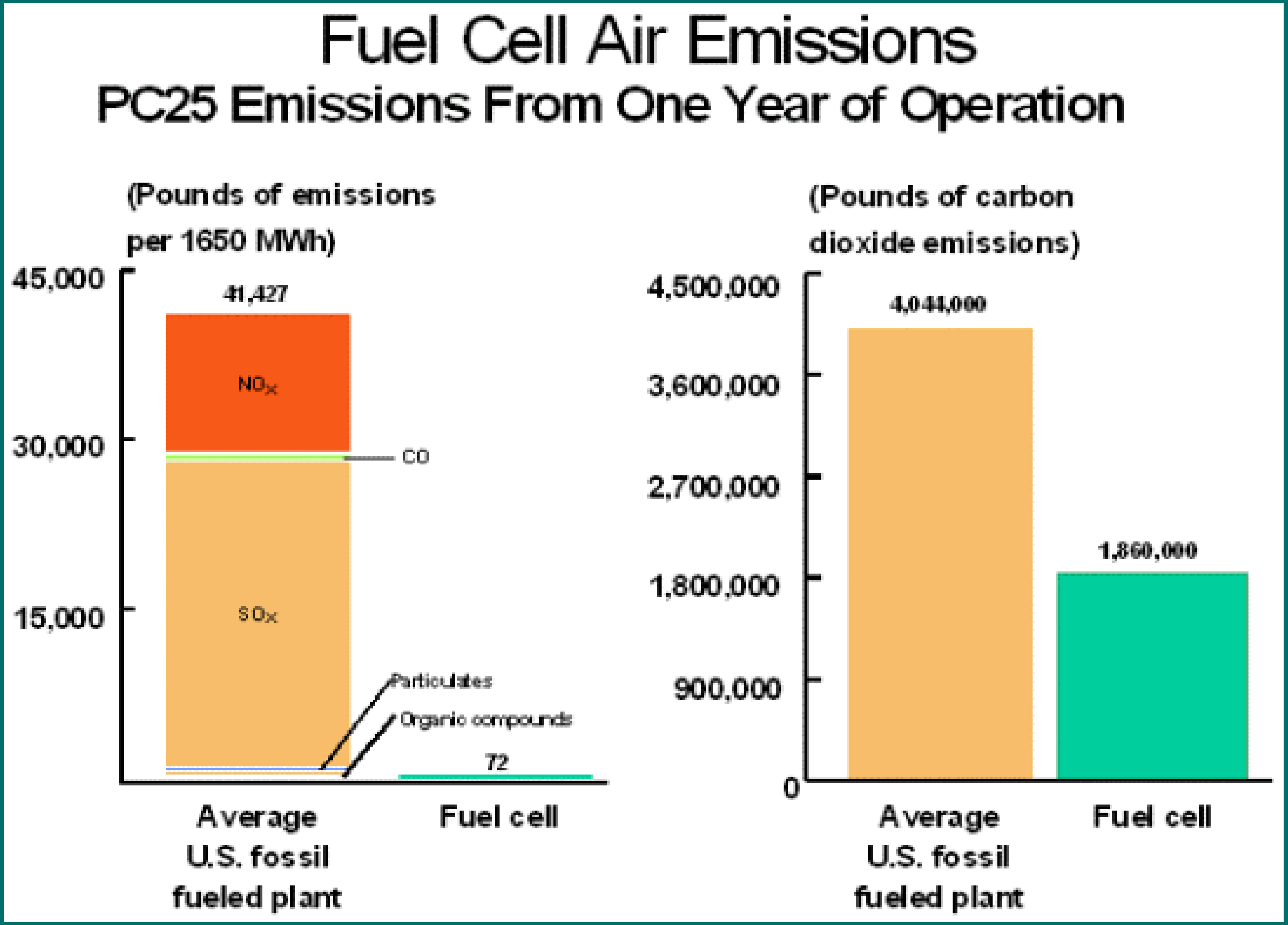
Further Advantages of PEM fuel cell

Quiet - no operational noise



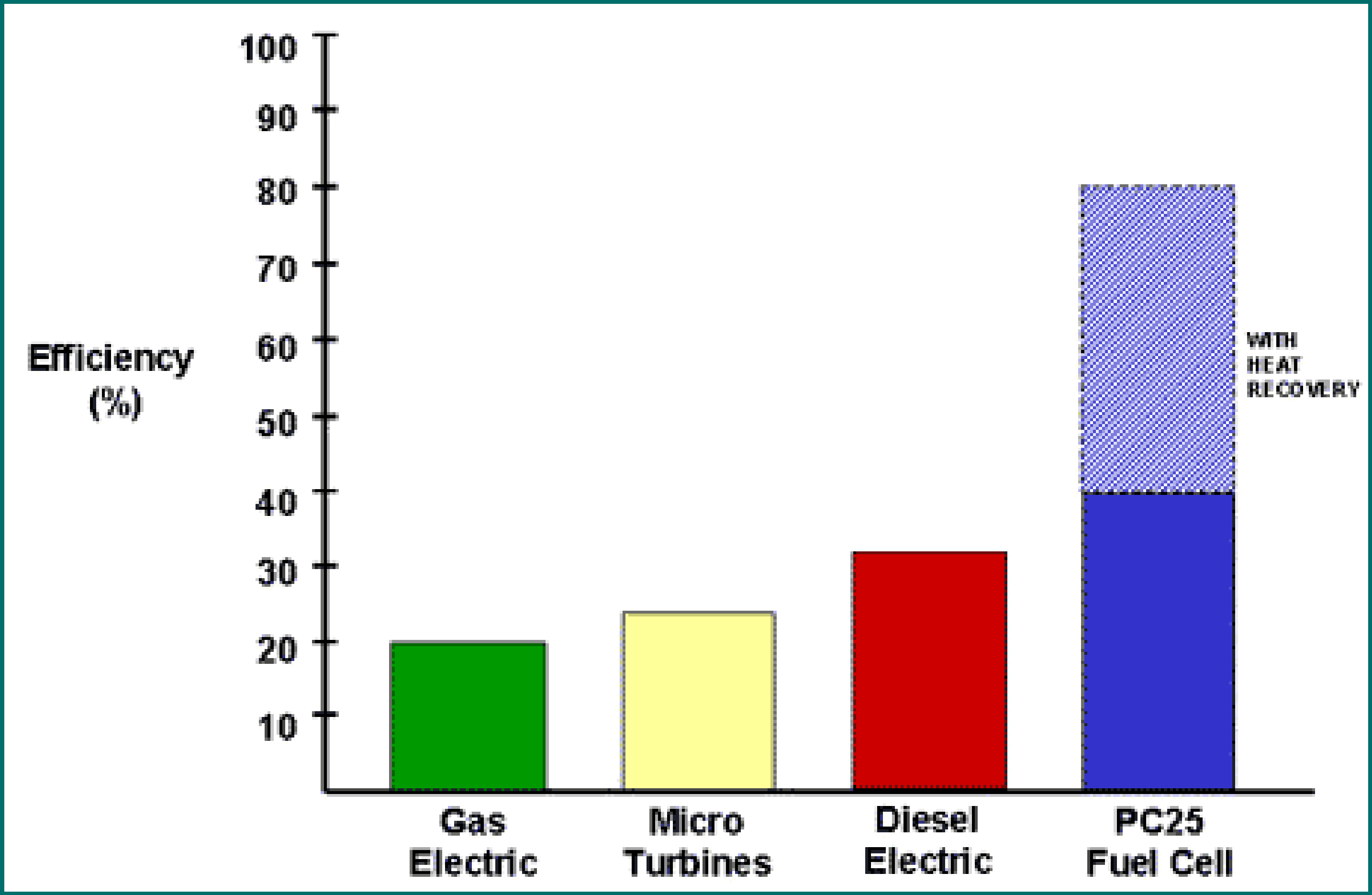
Low or No Emissions

Comparison of Emissions

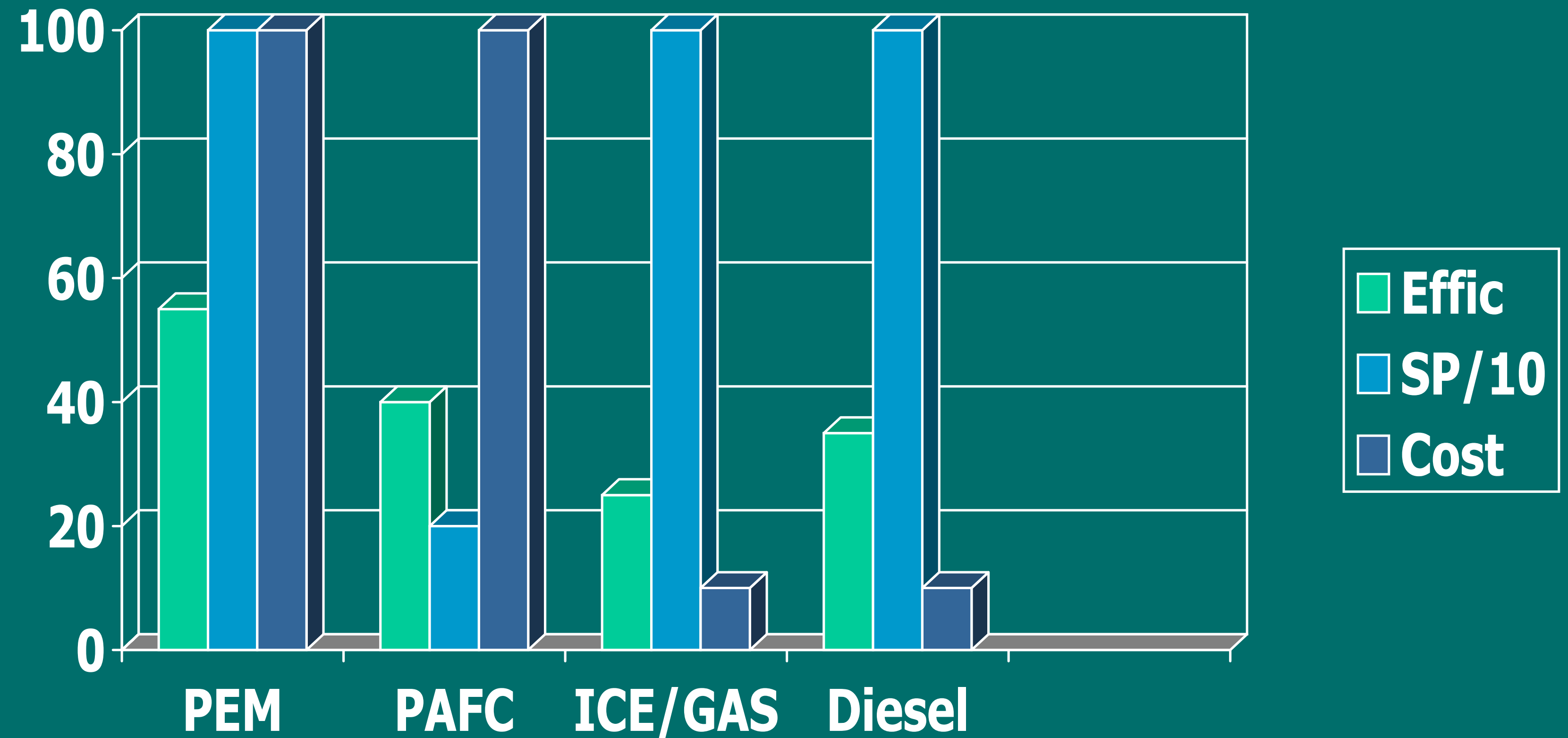


High Efficiency

Comparison of Fuel Cell Efficiency



Fuel Cells vs ICE



“The next great economic era will be powered by hydrogen” said Rifkin, president of the Foundation on Economic Trends

Drawing on a variety of well-balanced research studies, his basic premise is that the world must switch soon from a fossil-fuel economy to a hydrogen economy for three reasons:

1. The imminent peak of global oil production,
2. The increased concentration of remaining oil reserves in the Middle East one of the most politically and socially unstable regions of the world
3. The steady pollution and heating up of the world's atmosphere from fossil-fuel dependency.

Detailing the shortcomings of traditional energy sources in light of possible terrorist attacks, Rifkin then covers the merits of hydrogen as a "forever fuel"

Hydrogen Economy & Infrastructure

"Positive efforts made by government, corporations, environmentalists, and scientists to promote hydrogen as a clean, relatively safe, and potentially cheap alternative to carbon-heavy fuels"

Peter Hoffman, Author

Hydrogen Infrastructure is currently in the research and development stage

Institute for Research & Technology Transfer (IRTT)

Mission Statement

Supports the Regional Economic Growth and Enriches the Education Experience of the Students with Modern Technologies

Research And Development of New Technologies that Can Lead to Commercial Products

- Bridge the Gap between New Technologies Developed in the Laboratories and Industrial Commercialization
- Technology Transfer to Industry for Mass Production and opening New Job Opportunities

Current R&D Projects

- PEM Fuel Cells (Residential & Mobile Applications)
- Customized Bone and Dental Implants
- Automated Robotics and Manufacturing Islands – Pharmaceutical Companies
- Wind Turbines

IRTT Provides Outsourcing Opportunities for Small and Medium Size Companies to use IRTT's State of the Art Technologies and Advanced Systems to Enhance their Industrial Competitiveness

- Reduce Production Cycle Time and Bring Products to the Market Faster than the Competition

Offers Specialized Workshops

- To Sharpen the Students Skills with the State of the art Technology and Enrich their Education Experience with Practical Knowledge and Faculty at the Cutting Edge of Technology.

HYDROGEN INSTITUTE

R&D of Alternative/Renewable Sources of Energy

- PEM Fuel Cells
- Membraneless Fuel Cells
- Wind Turbines

Technical & Economical Challenges of Fuel Cells:

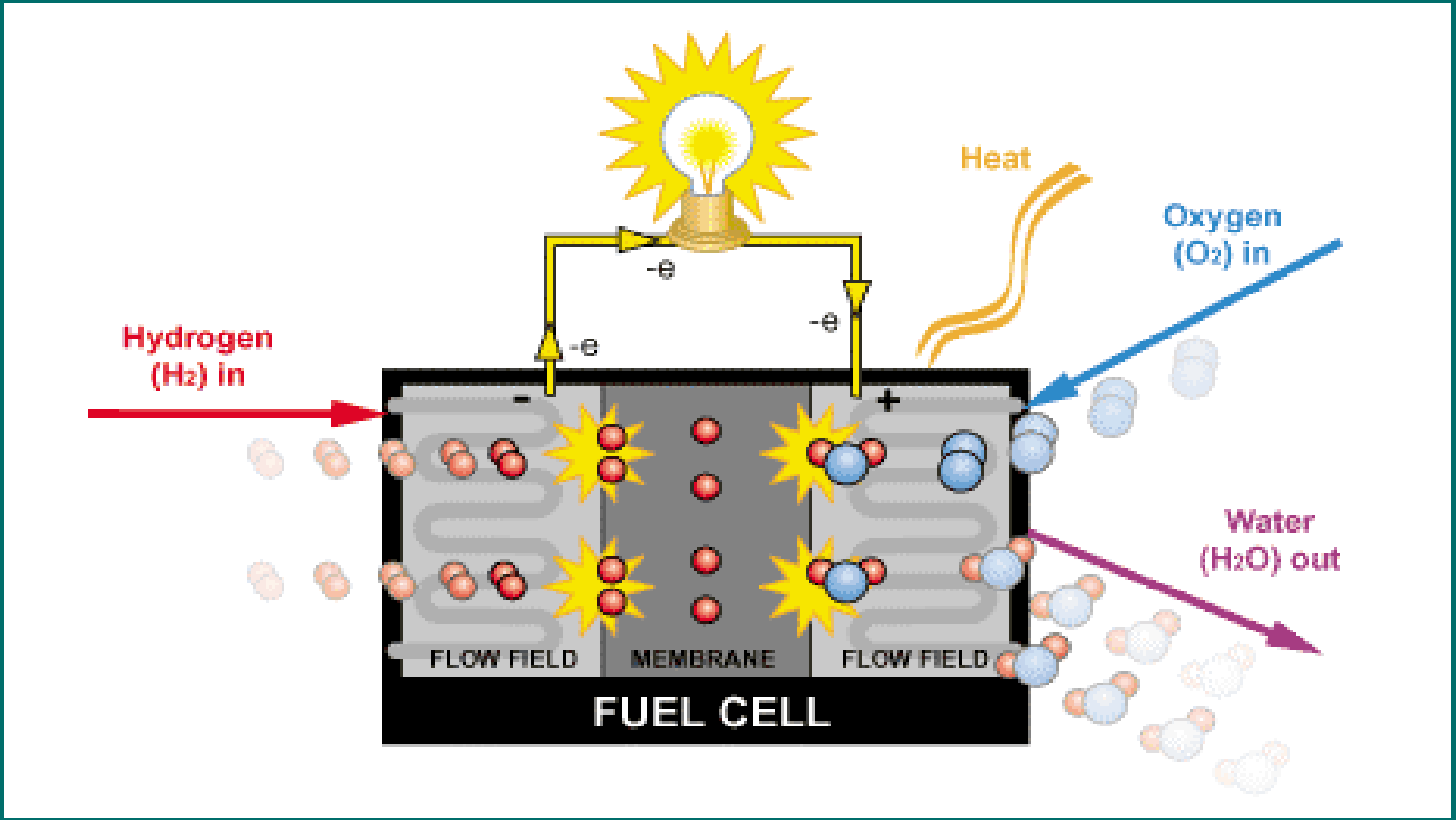
FC	Advantages	Challenge
PEM	Quick Start/up	Thermal & water Manag.
		MEA Durability
SOFC	12 hrs Start up	Thermal Cycling
MCFC	12 hrs start up	Thermal Cycling

Cost must be reduced at least five fold

PEM Fuel Cells

- According to the U.S. Department of Energy, " Proton Exchange Membrane (PEM) fuel cells are the primary candidates for light-duty vehicles, for buildings, and potentially for much smaller applications.
- They provide clean energy and operate at relatively low temperatures (about 200 degrees F), produce high power density and can vary their output quickly to meet shifts in power demand and are suited for applications such as in automobiles, where quick startup is required.

Fuel cell Operation



DOE Targets/Challenges for PEM

- **MEA Tolerance for CO in Reformed H_2**

With dry composition of 40% H_2, 21% CO_2, 39% N_2, and 10-15 ppm CO

  - High Temperature MEA > 120 C
  - Membraneless

- **MEA Durability**
  - 40,000 hrs with < 10% Degradation, <1% Cross Over, Area Resistance < 0.1 ohm.cm^2

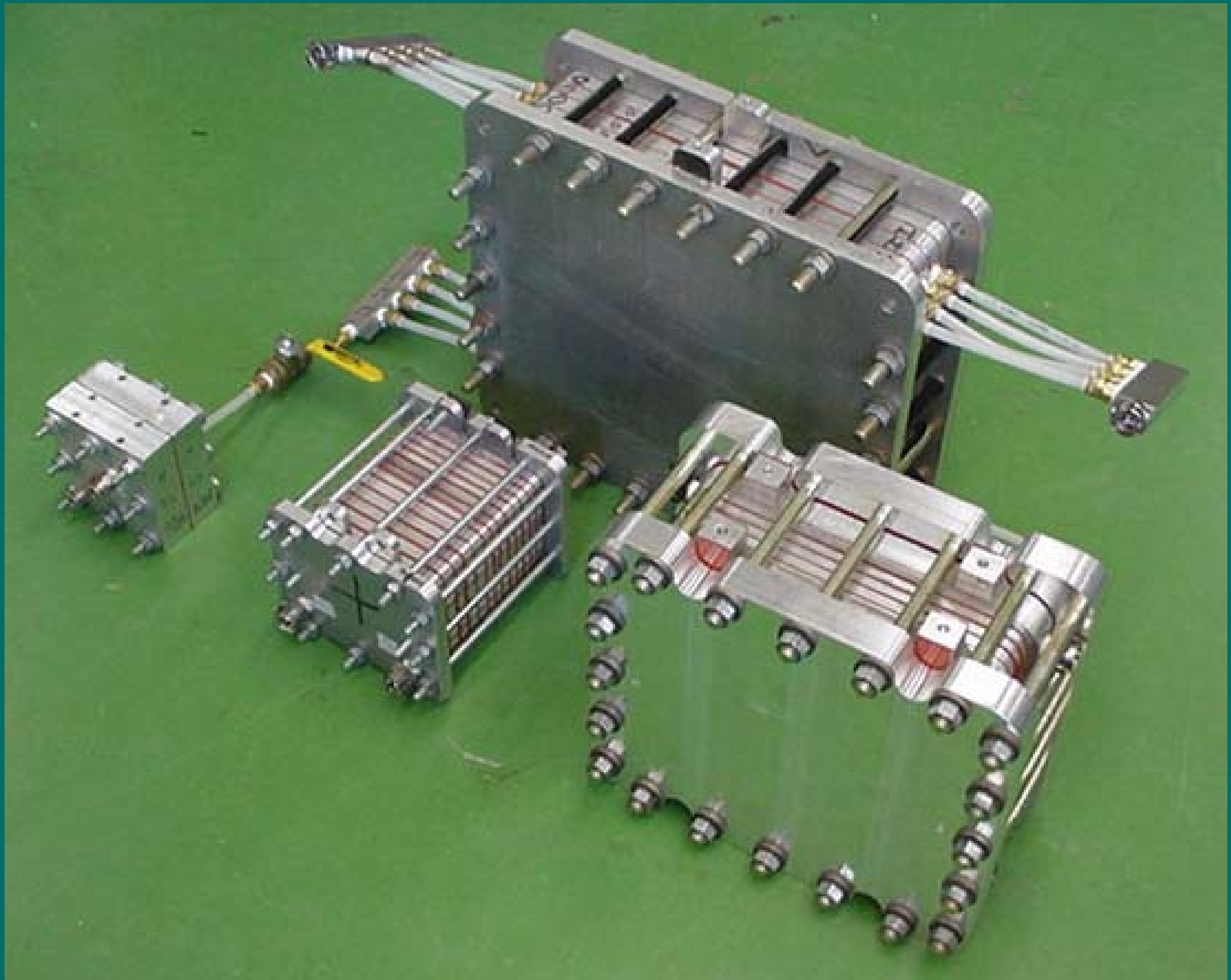
- **Cost**
  - $1,500 / kW for PEM Power System
  - $10/kW for MEA

- **Efficiency**
  - 35% to 50%

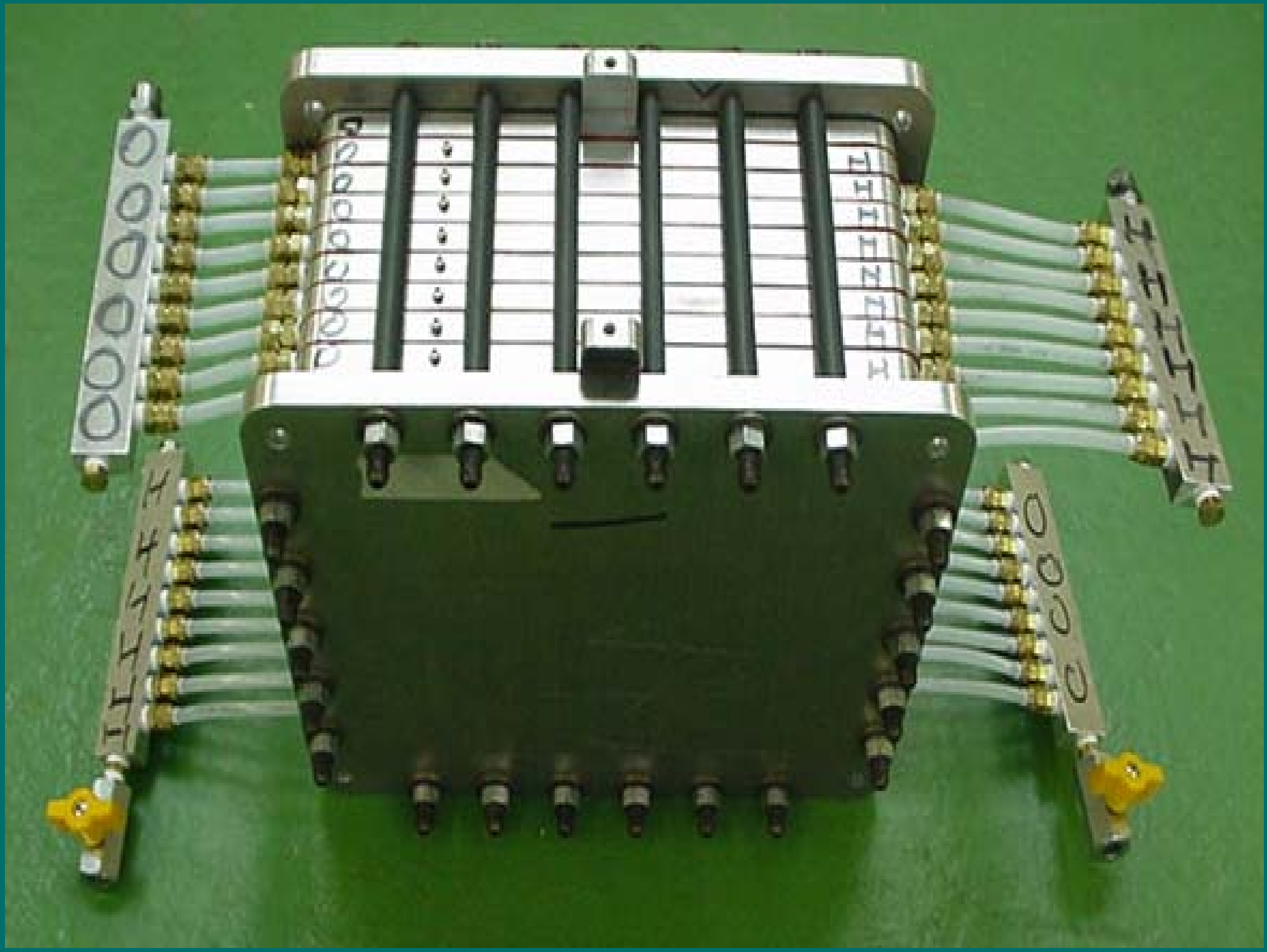
Economic Evaluation of Bipolar Plates Heat loss/year due to Electric Resistance

FC Unit Size	Aluminum	Graphite
1 kw	$0.01	$2.13
5 kw	$0.063	$10.67
10 kw	$0.12	$21.35
20 kw	$0.25	$43.0
50 kw	$0.63	$107.0
100 kw	$1.26	$213.53
500 kw	$6.296	$1068.0

Second Year Stack Designs and Testing



External Manifold Design

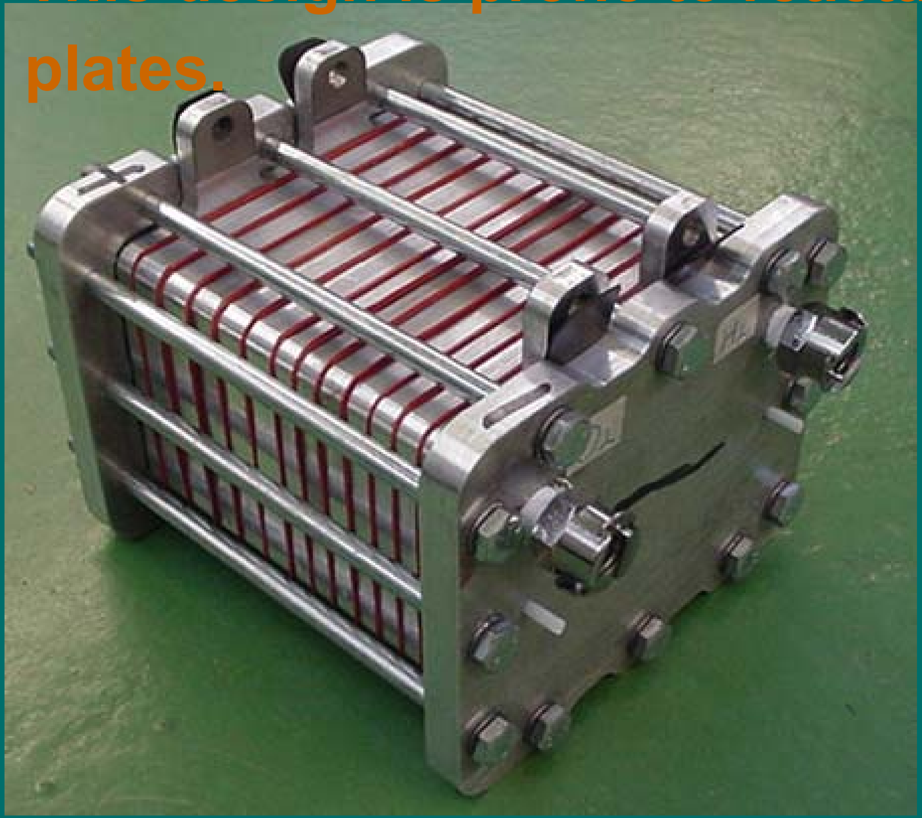


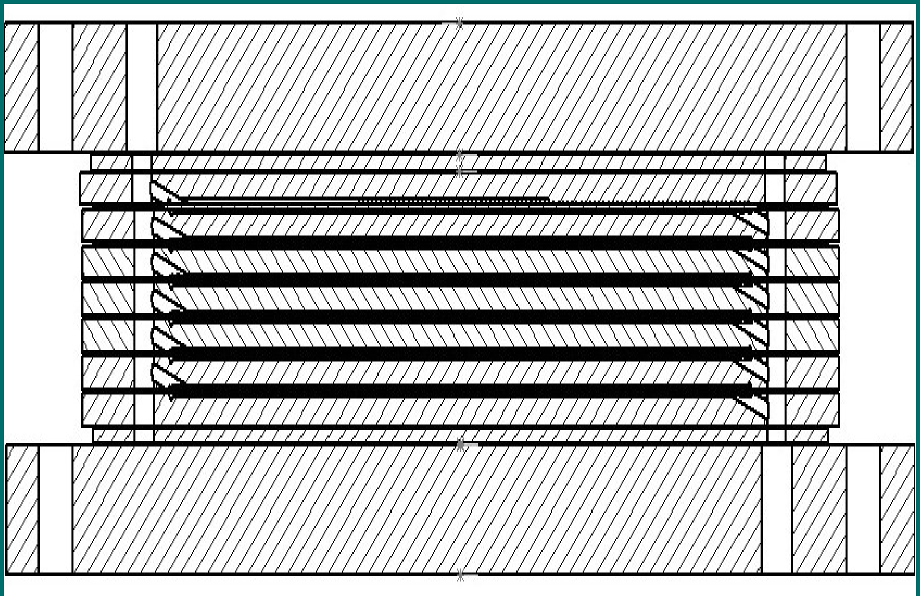
External Manifold Design

- **Manifolds are Labor Intensive**
- **MEA(s) are Too Large to Fabricate**
- **Manifolds are Prone to Leaks**
- **No Possibility of Leaks from the Bipolar Stack Plats**

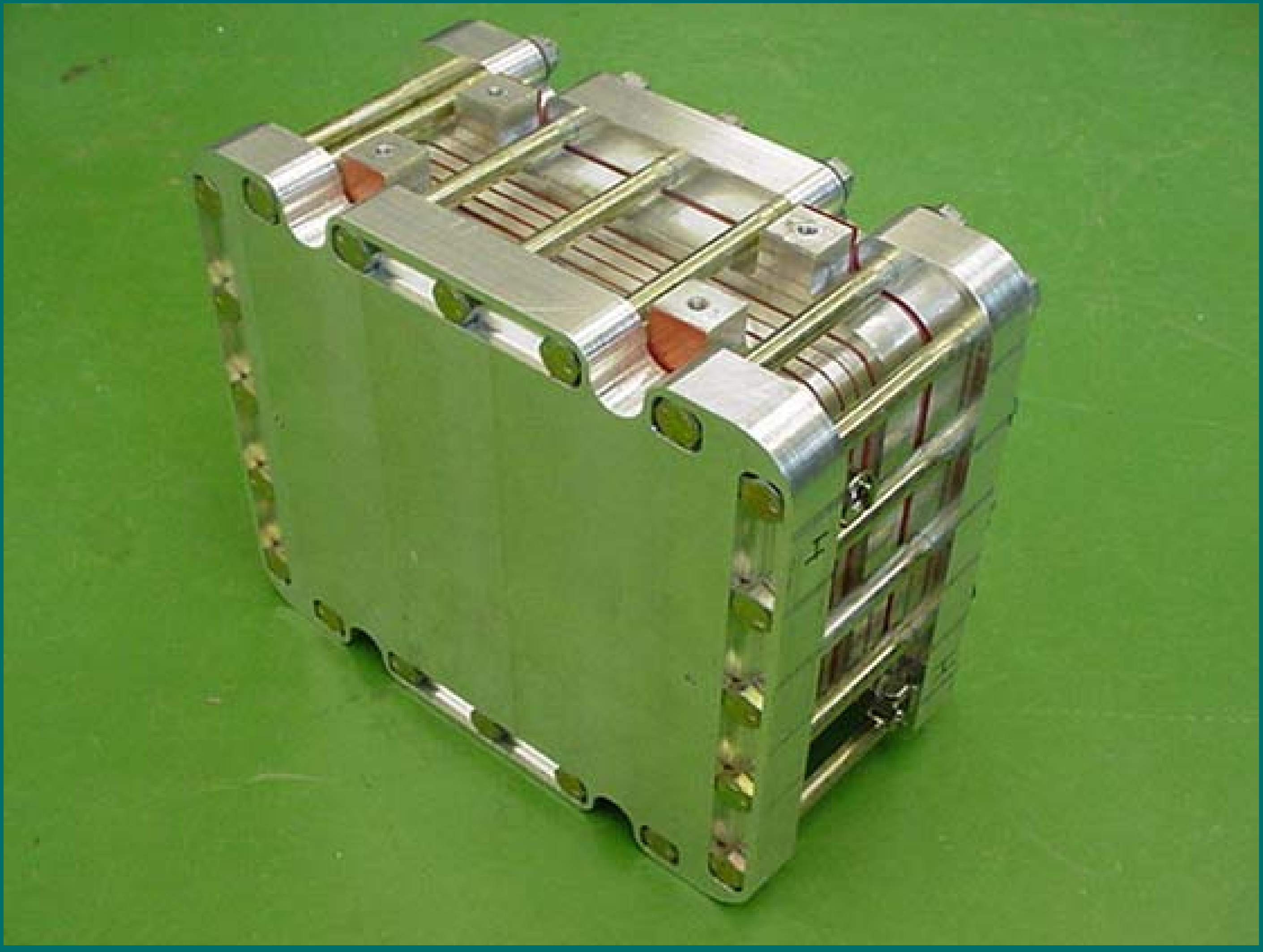
Stack design (Internal Manifold)

An internal manifold fuel cell stack was fabricated using our recent research findings, such as plates and gaskets thickness as well as coating and gaskets materials. (Note: This design is prone to reactant gas leak from the end plates.





Final Stack Design

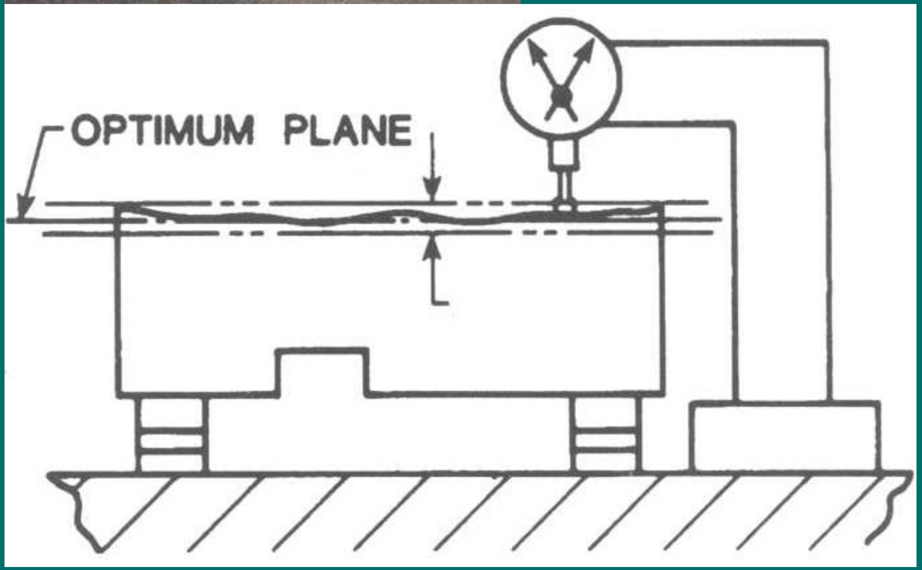


Final Stack Design

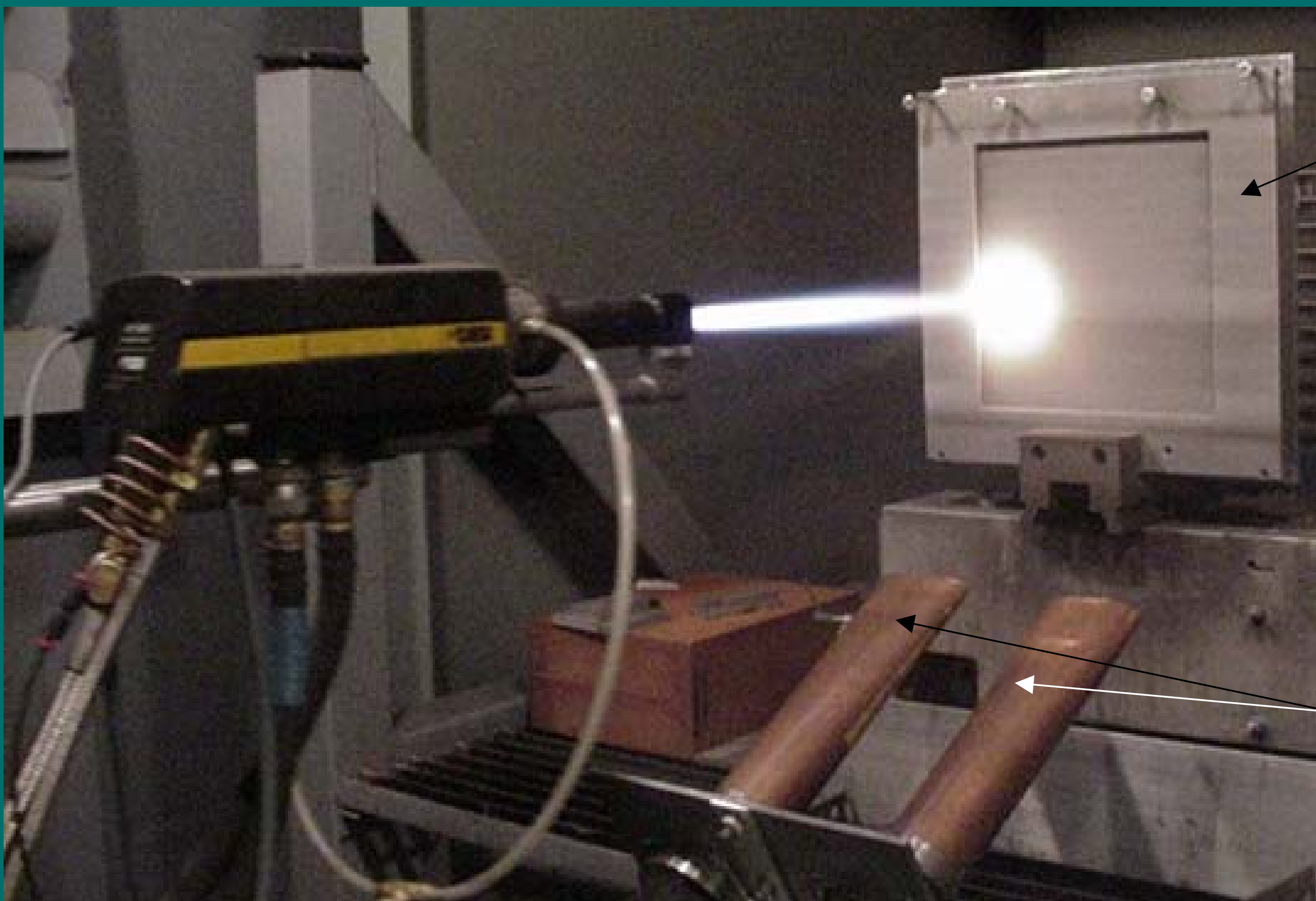
- No external gas leaks from:
  - between front and bipolar plates
  - between bipolar plates
- Medium size MEA, easy to fabricate
- Bipolar plates are thin
- Gasket is 0.020 inch thickness


SABRE
MILACRON
SABRE

Equipments for flatness measurements



Research procedure to reduce deformation



MASK

AIR
COOLING
TUBE

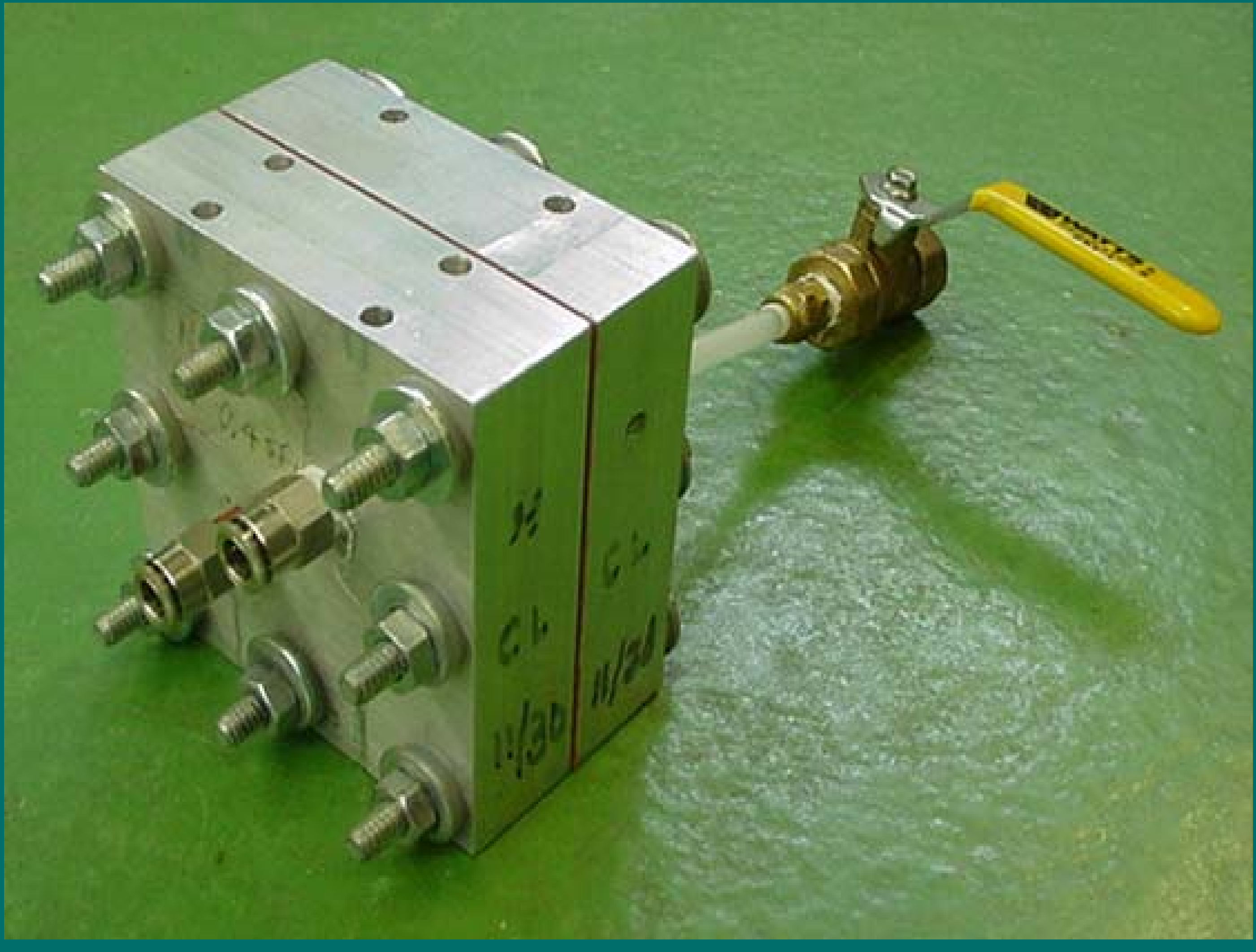
55 Ton Press for MEA Fabrication

55 Ton Press for MEA Fabrication

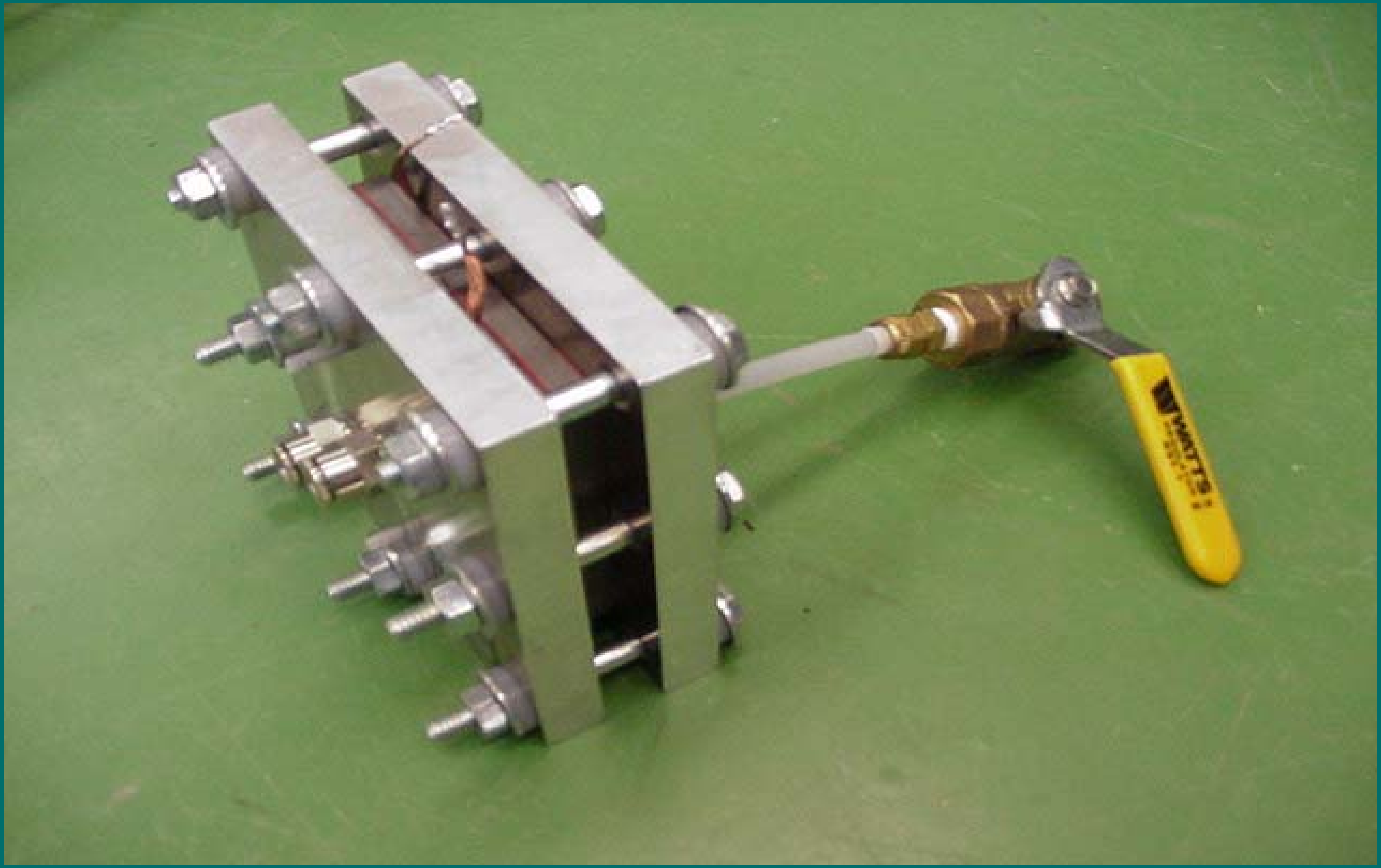
Composition of Membrane Electrode Assembly (MEA) : (Carbon diffusion layer+ Mix of carbon, Pt(Catalyst) and liquid Nafion

Adhesion requirement for MEA (high temp & pressure)

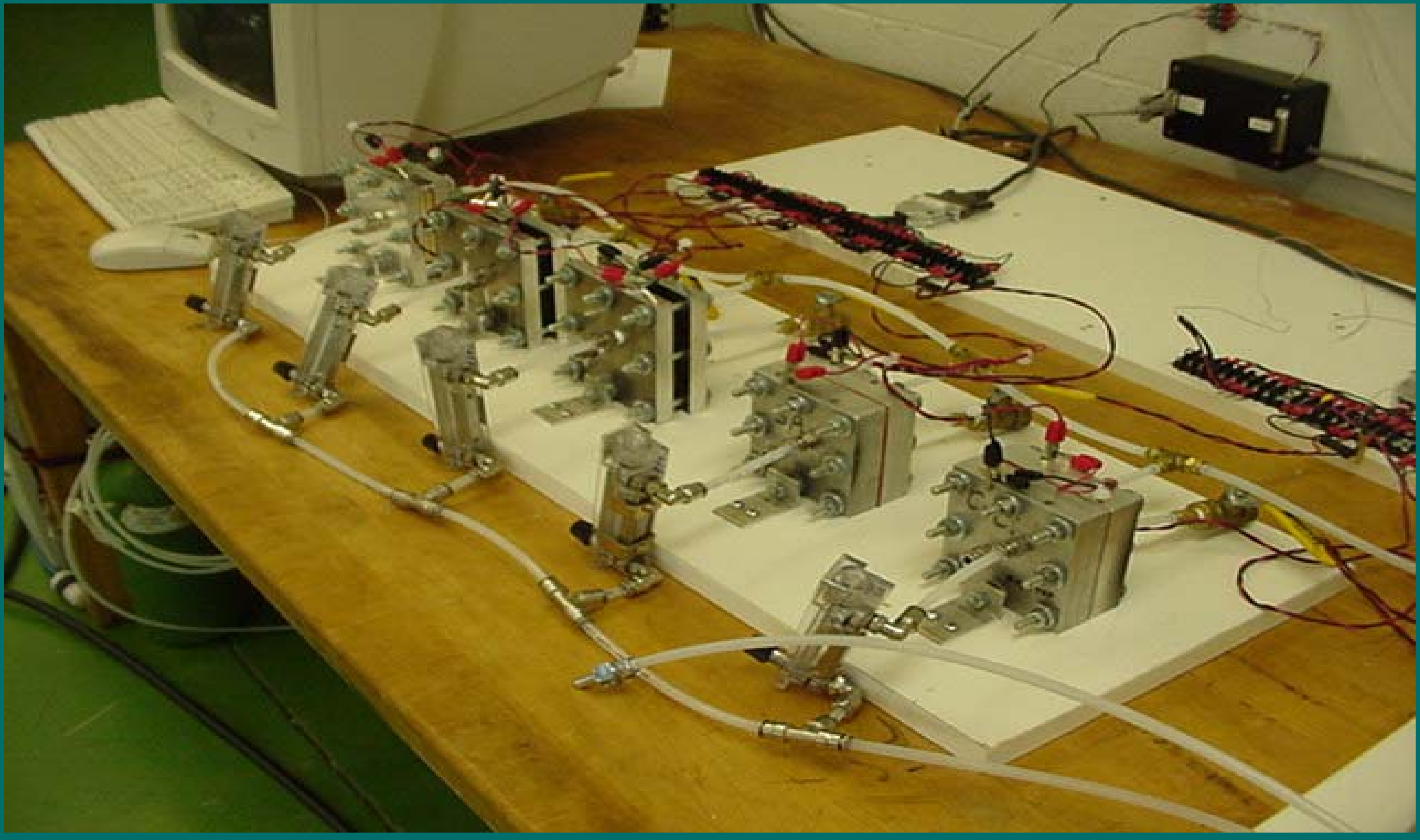
- Two heating plates with temp controller and 4 releasing springs
- 55 ton hydraulic pressure



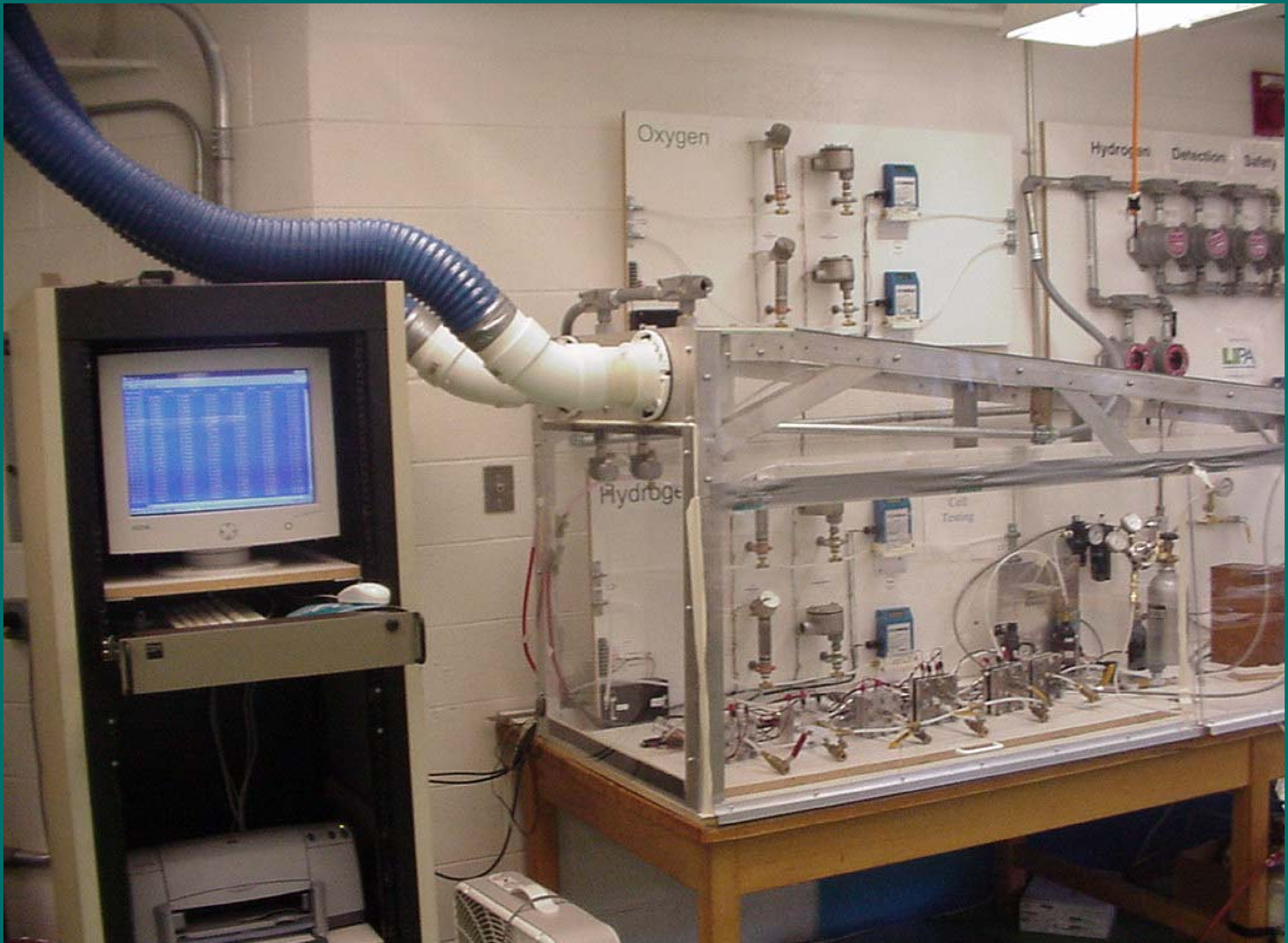
Graphite Bipolar Plates



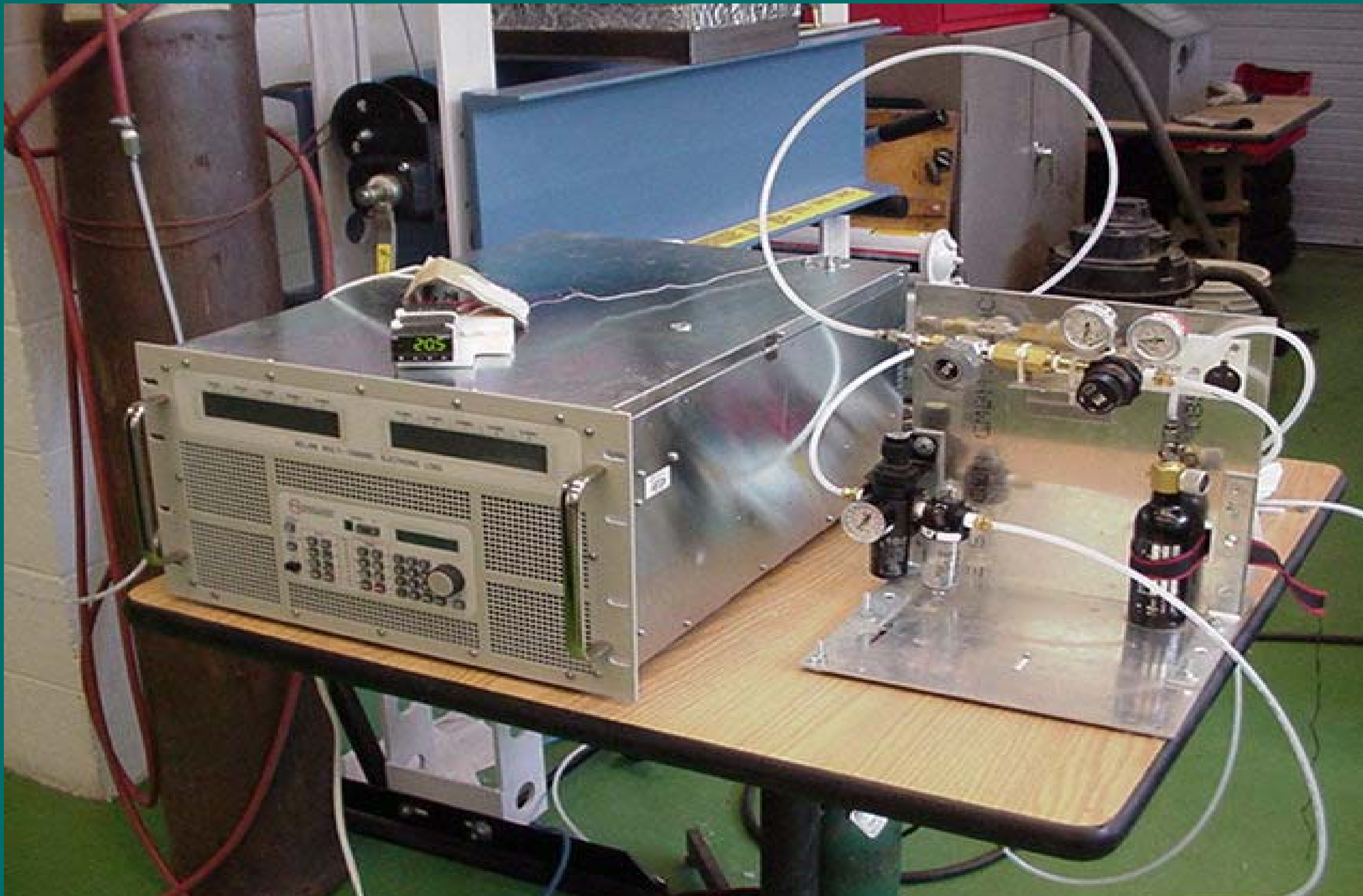
Five Single Cells – 1 Gold Plated, 2 Graphite Composite, and 2 coated AL



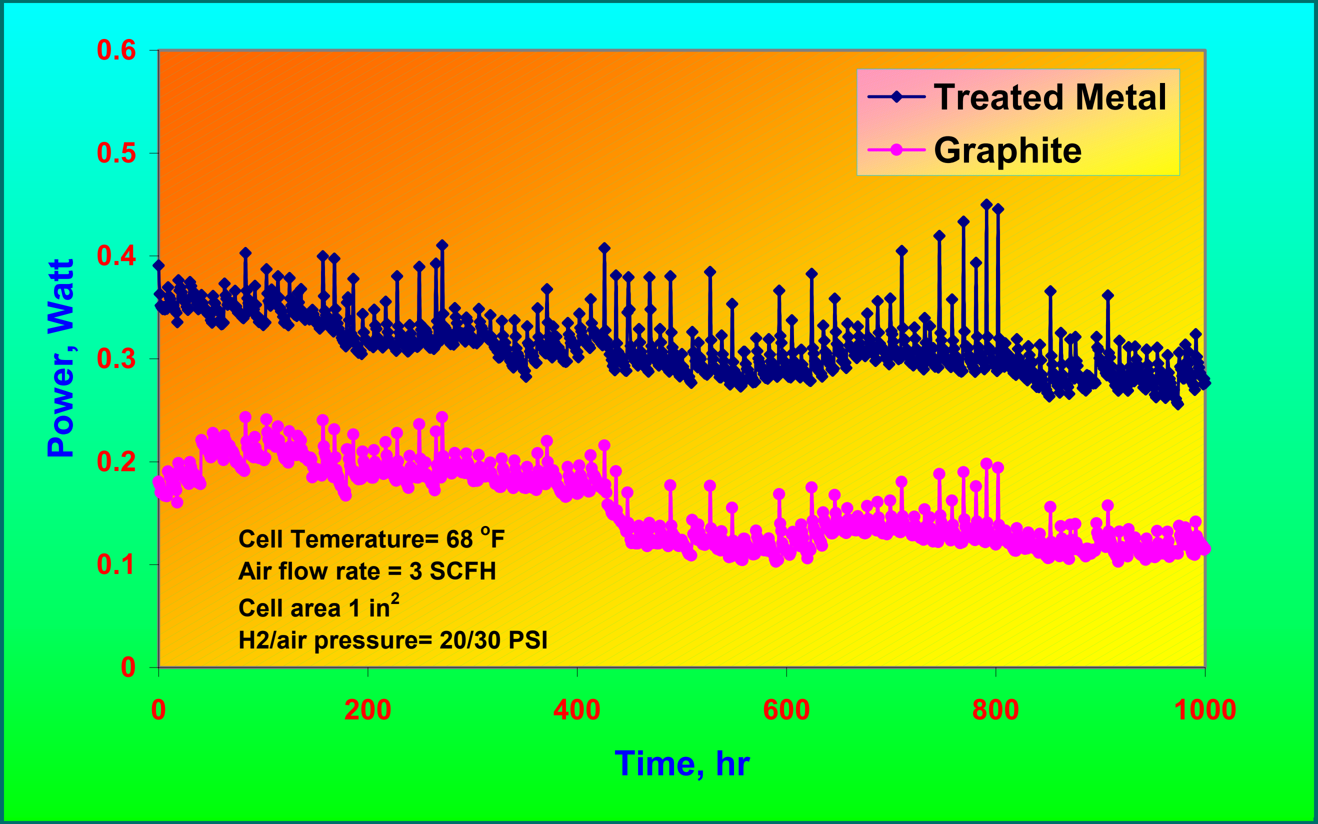
Hydrogen Safety System For Fuel Cell Testing



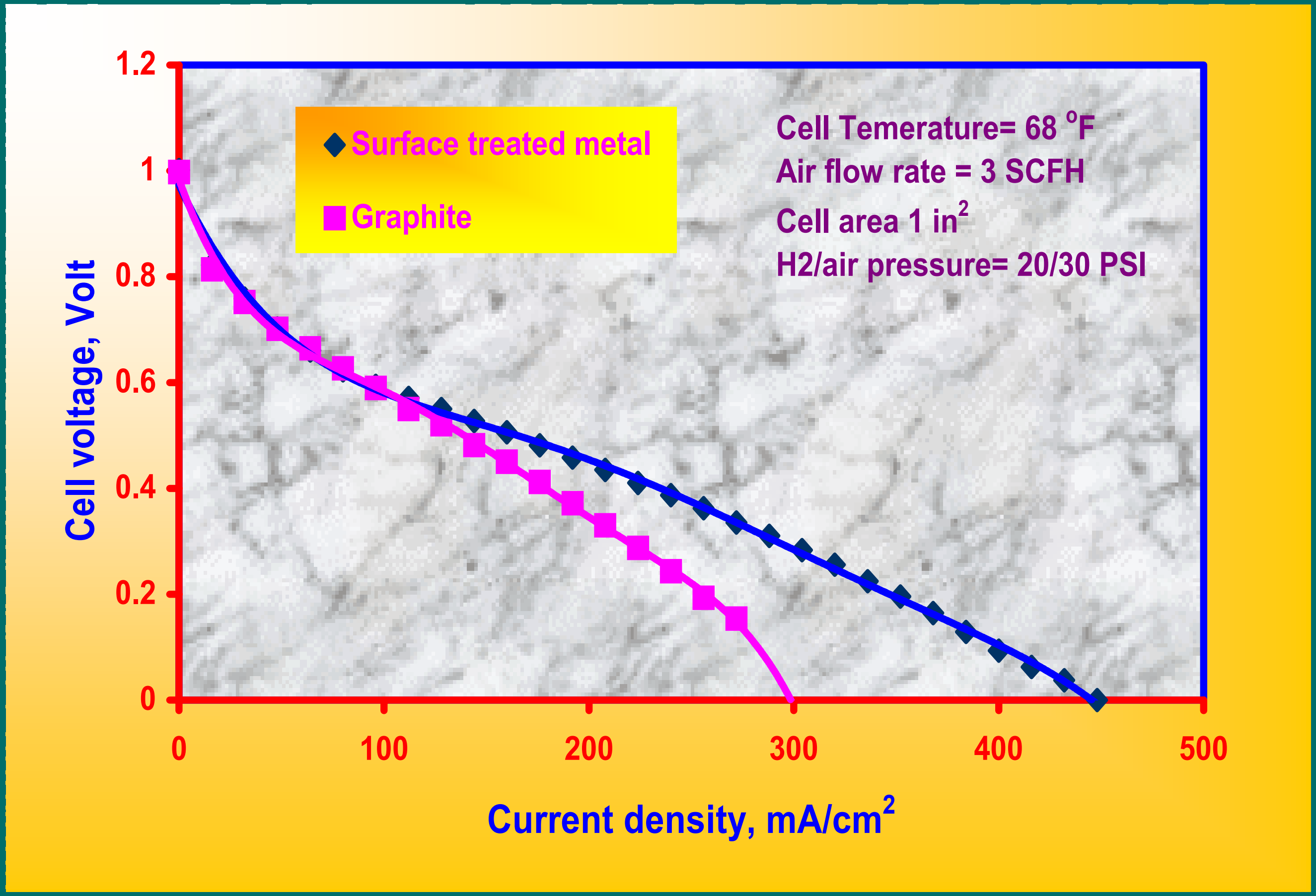
Variable Loading Testing M/C



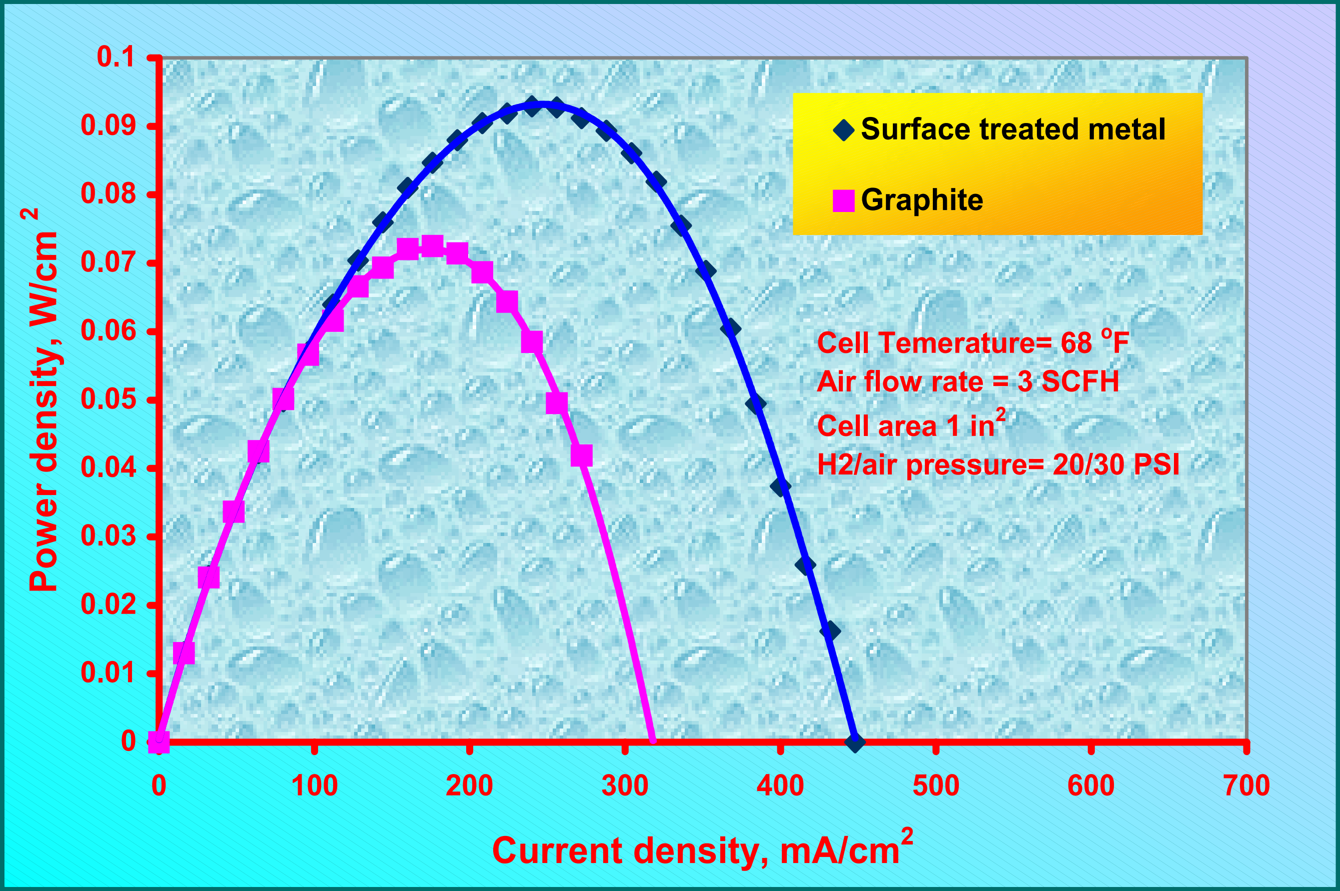
Life Time Test of Metallic vs. Graphite Bipolar Plates



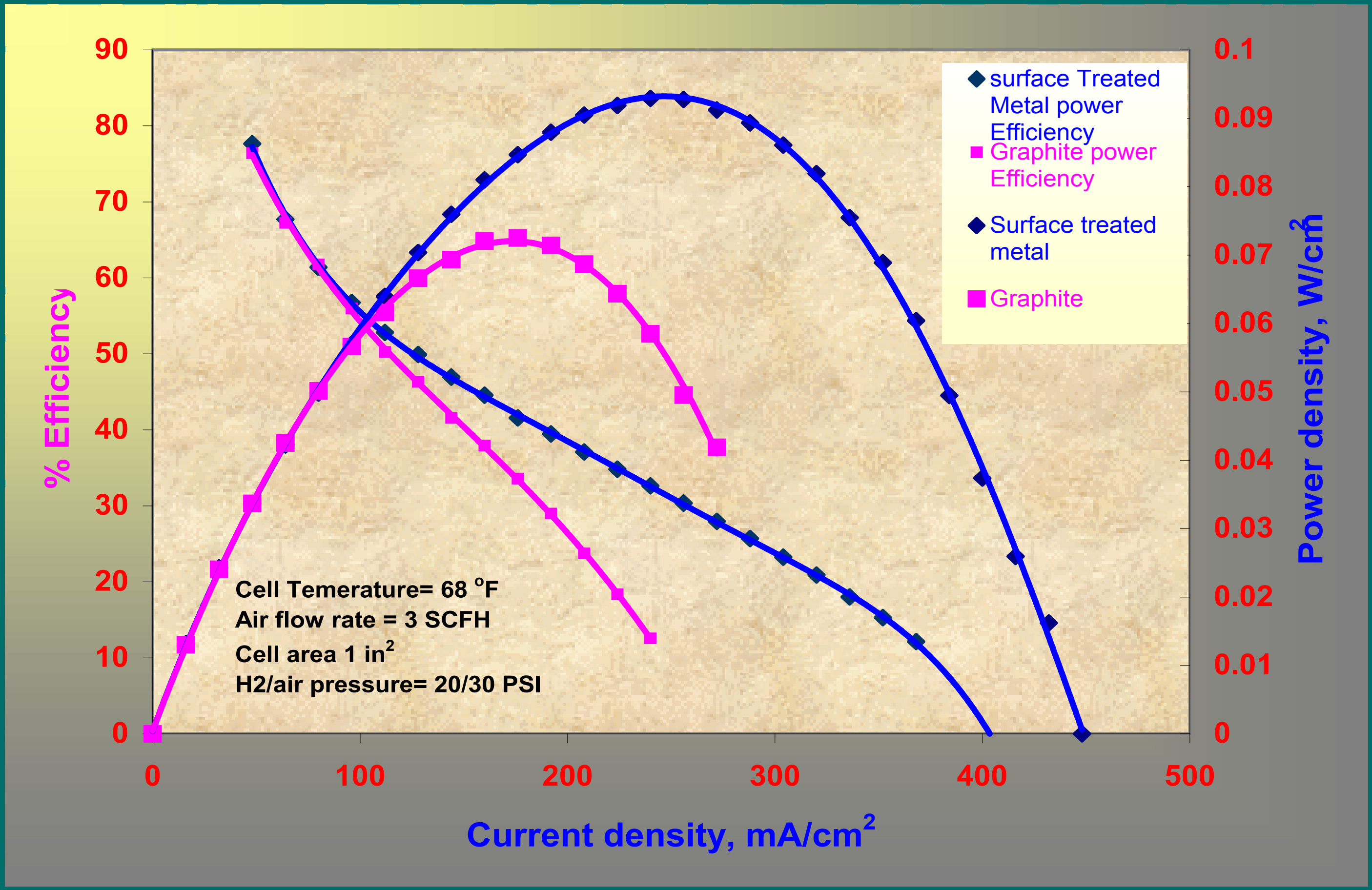
Polarization Curve For Comparison Between Surface Treated Metal and Graphite



Power Density Curve For Comparison Between Surface Treated Metal and Graphite

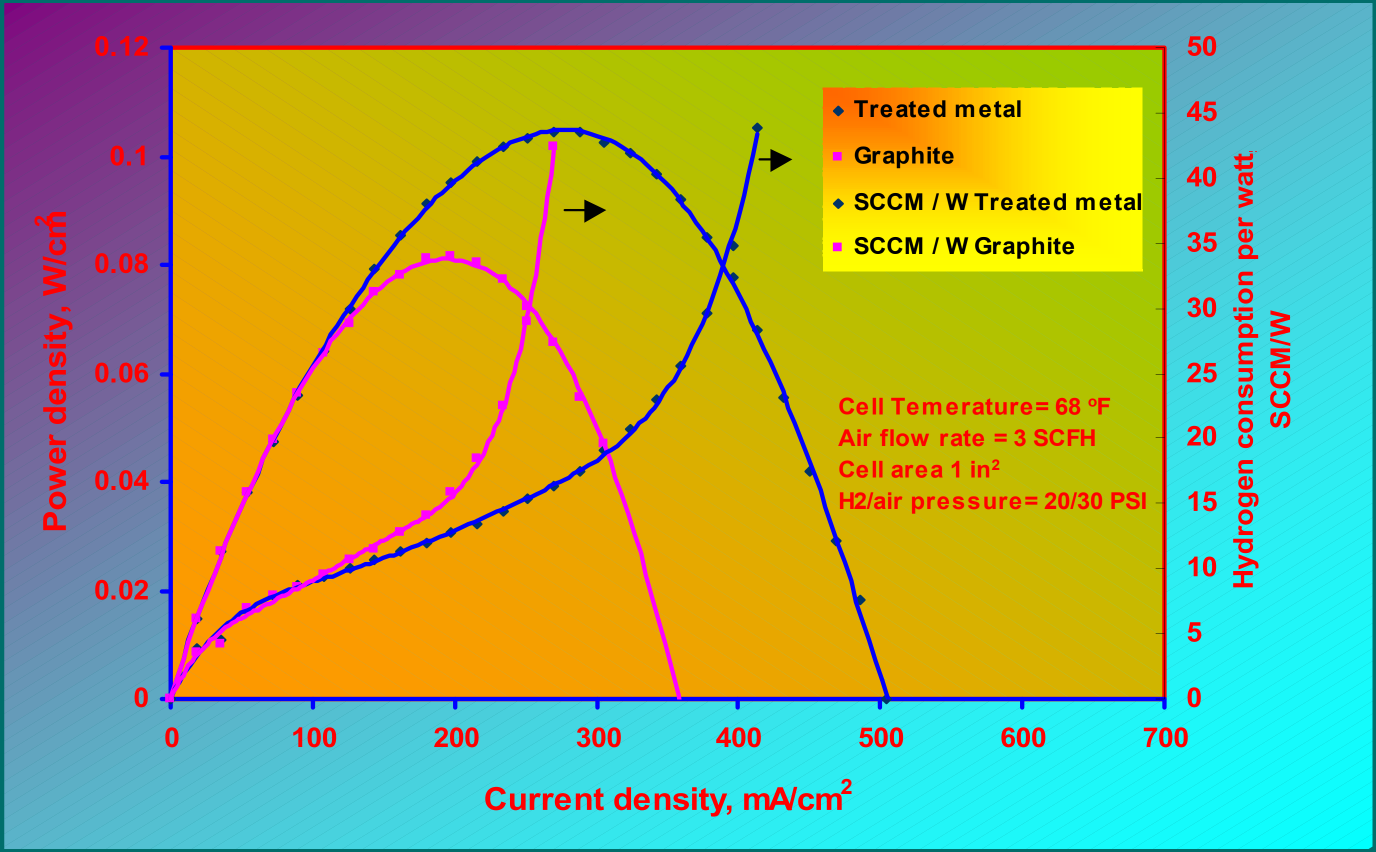


Power Density & Efficiency Curve For Comparison Between Surface Treated Metal and Graphite



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 metal vs. graphite bipolar plates.



Economic Viability of Metallic Plates

Fixed Costs (Materials and Manufacturing Costs) Base on 14.6 x 14.6 cm active area fuel cell

	Graphite	Aluminum
Material cost (per lb)	$10.00	$ 2.80
Material weight per plate (lb)	0.859	1.12
Material cost (per plate)	$ 8.59	$ 3.14

Mass production cost

	Graphite	Aluminum
Tooling cost (Injection molding / Die casting) minimum 250,000 plates	$35,000.00	$32,000.00
Cost of Secondary Operation (per plate)	$10.00	$ 20.08
Total cost per each plate	$ 13.88	$ 23.22
Bipolar plate cost per (cm^2)	$ 0.065	$ 0.109

Running Costs - Hydrogen Consumption

	Graphite	*Aluminum*
Hydrogen consumption (SCCM/watt)	12.5	11.4625
Efficiency		8.30%
Hydrogen consumption (Liter per 1 kW hr)	750	687.75

Summary of Fixed and Running Costs

	Graphite	*Aluminum*
Fixed Cost of bipolar plates per kilowatt	$ 130	$ 266
Running Cost of Hydrogen per kilowatt hour	0.405	0.372

Comparison of energy cost generated by aluminum and graphite bipolar plates

IRTT Fuel Cell Development

- Metallic bipolar plates
- Design and development of new serpentine configurations – Patent Pending#1
- New power stack design – Patent Pending#1
- New manufacturing technique and high corrosion resistance metal treated bipolar plates – Patent Pending#2

IRTT PEM Stack Design Advantages

- Rigid and durable
- Internal manifold
- Leak free
- compact
- Suitable for all applications
- More suitable than graphite for transportation applications
- Does not require elaborate cooling system like graphite – Aluminum is much more conductive than graphite

IRTT's New Technology in a Nutshell

- High corrosion Resistance with high electrical and thermal conductivity Metallic Bipolar Plates – (Low Hydrogen Consumption 12% less than Graphite and Simple Cooling System)
- Compact, rigid and leak free stack design with internal manifold

Note: IRTT PEM Technologies cover all fuel cell's mobile and stationary applications

Potential Markets for PEM Technology

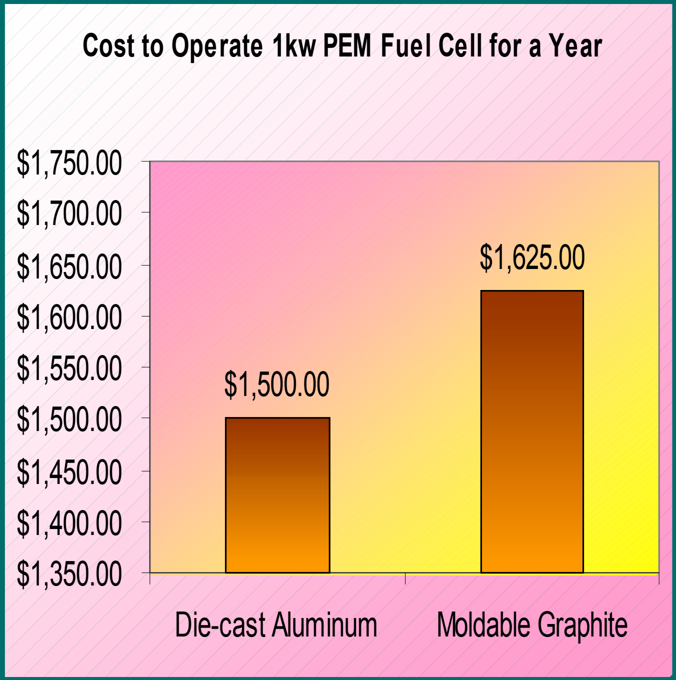
The main market for PEM is the BACK UP POWER

- Telecommunication Towers
- Hospitals
- Banks
- Police Precinct
- Peak load Shaving

These markets require max lifetime of 4000 hrs

Projected PEM Fuel Cell Market

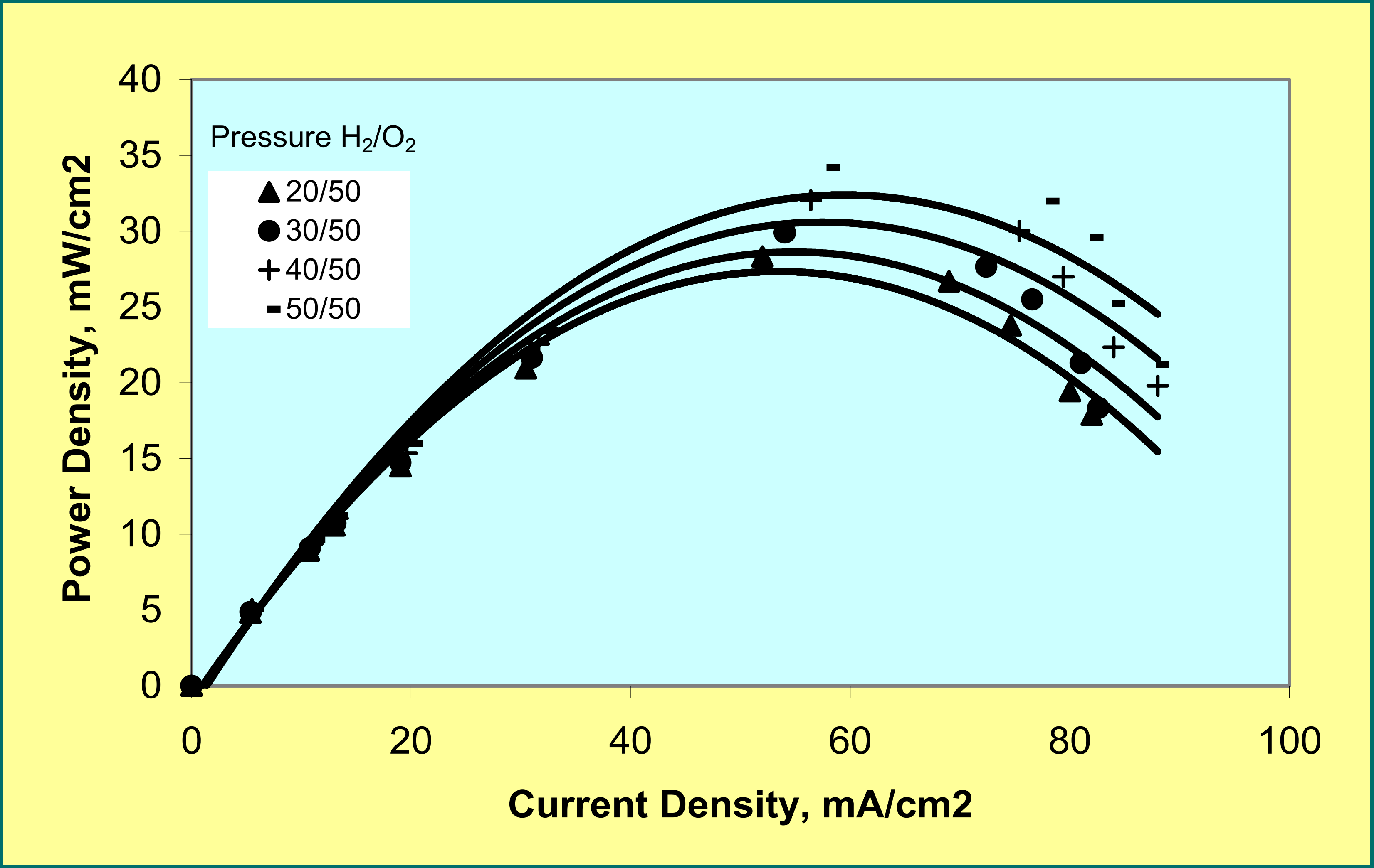
- Local back up Power Systems
- Estimated at one MW for the first year
- $5000/kW – Market size for first year is $ 5 million
- Hydrogen Savings per kW/year $125 – For backup power about 800 hrs a year – Hydrogen Savings $12.5/kW of back up power over one year
- Total Savings for one MW in the first year = $12,500



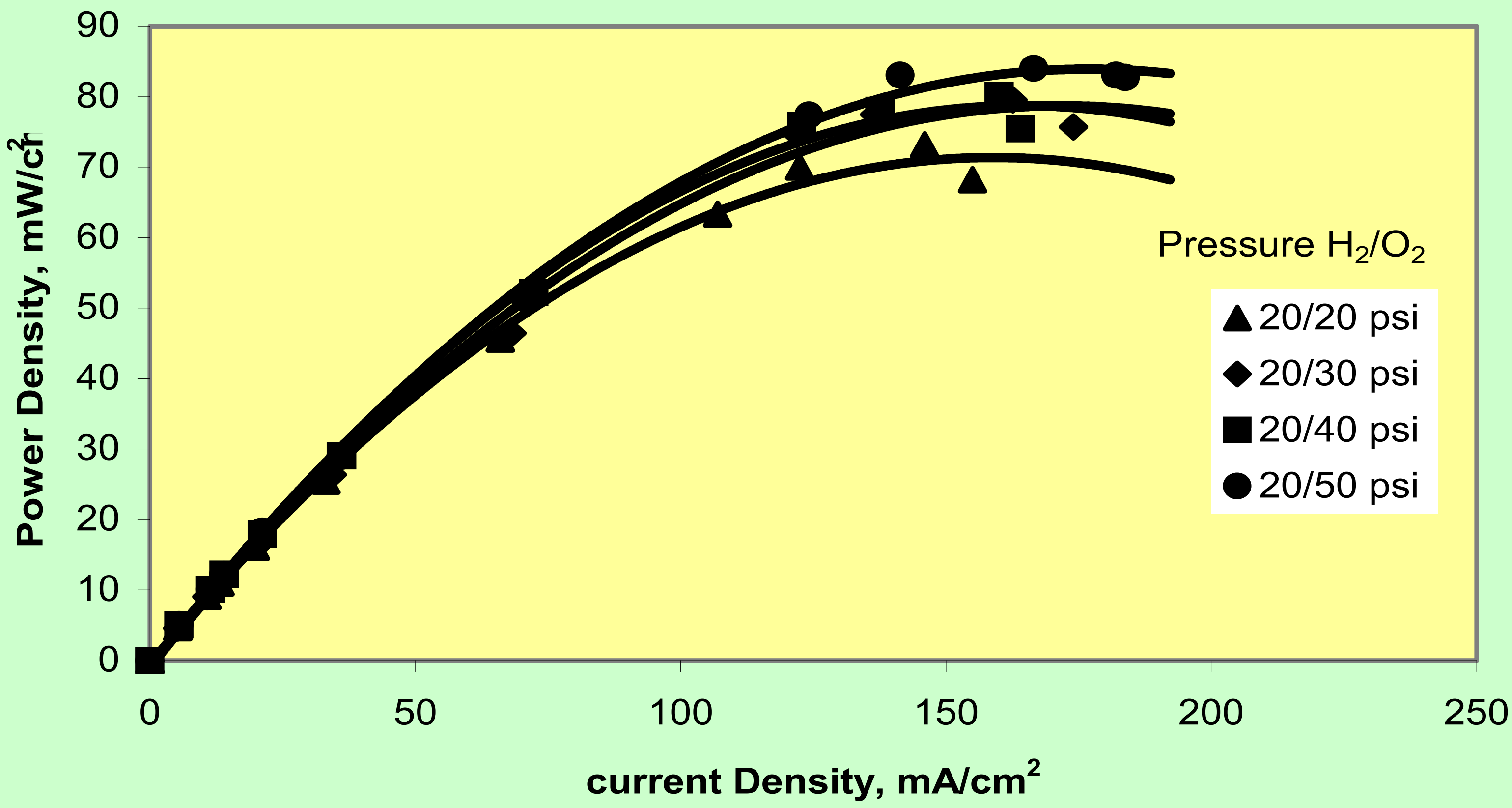
To Put the New Technology under one Umbrella we are Developing The HYDROGEN INSTITUTE

- Provide Awareness of Alternative Sources of Energy to the Public.
- National Research and Education Institute for undergraduate, postgraduate, and continuing education studies in alternative sources of energy:
  - Fuel Cells
  - Wind
  - Solar
  - Geothermal

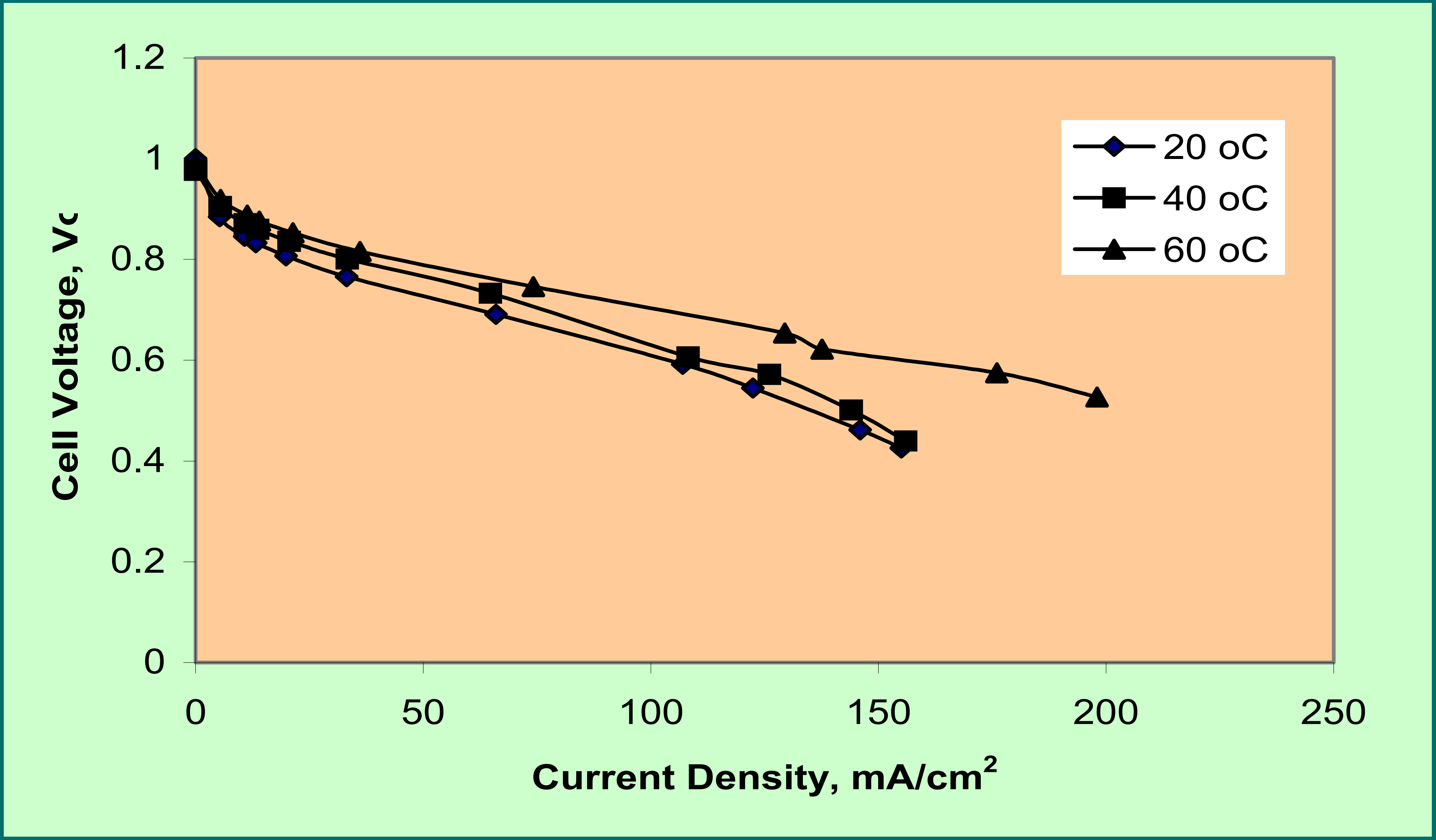
Effect of Hydrogen Pressure on Power



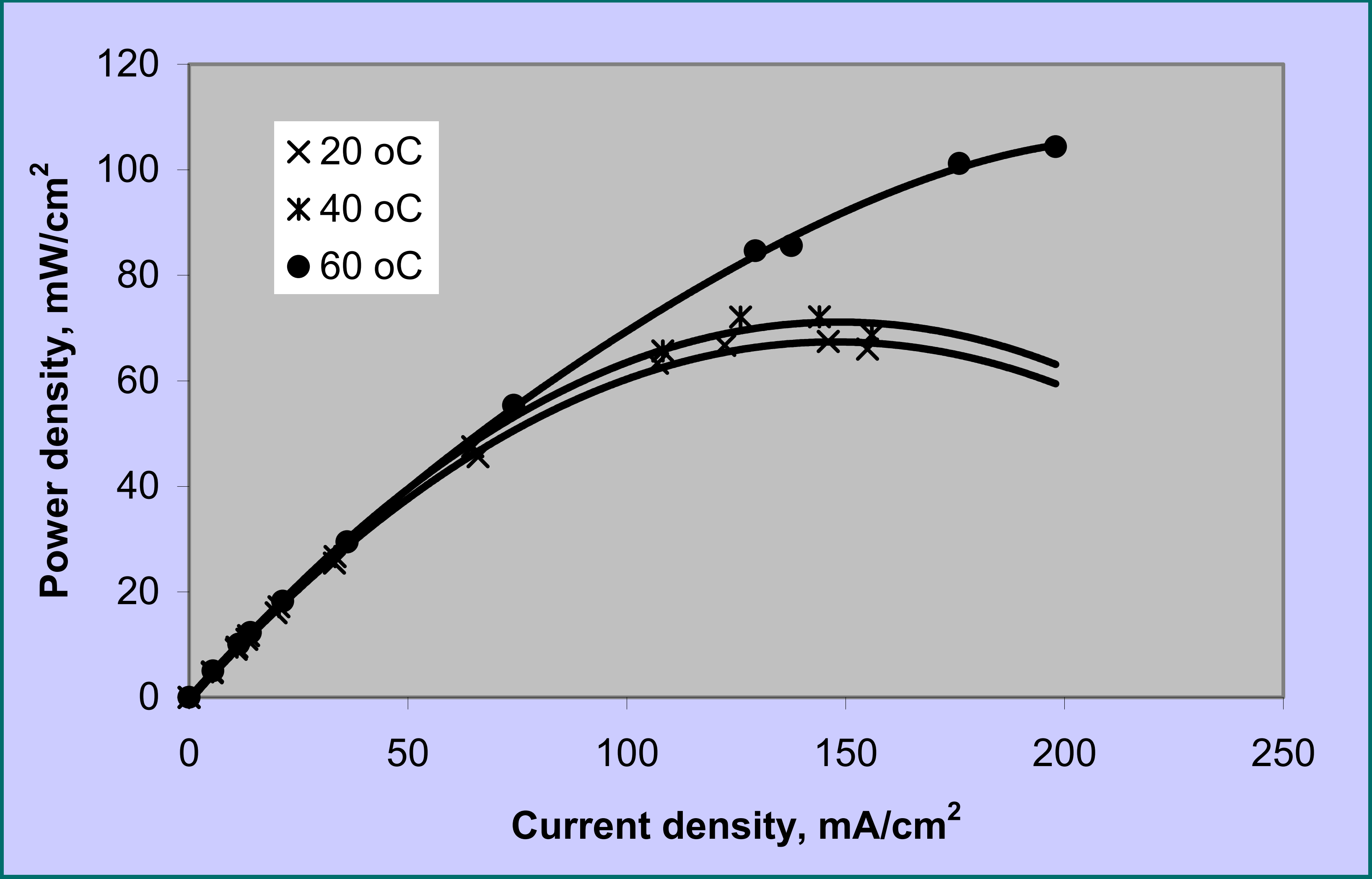
Effect of Oxygen Pressure on Power



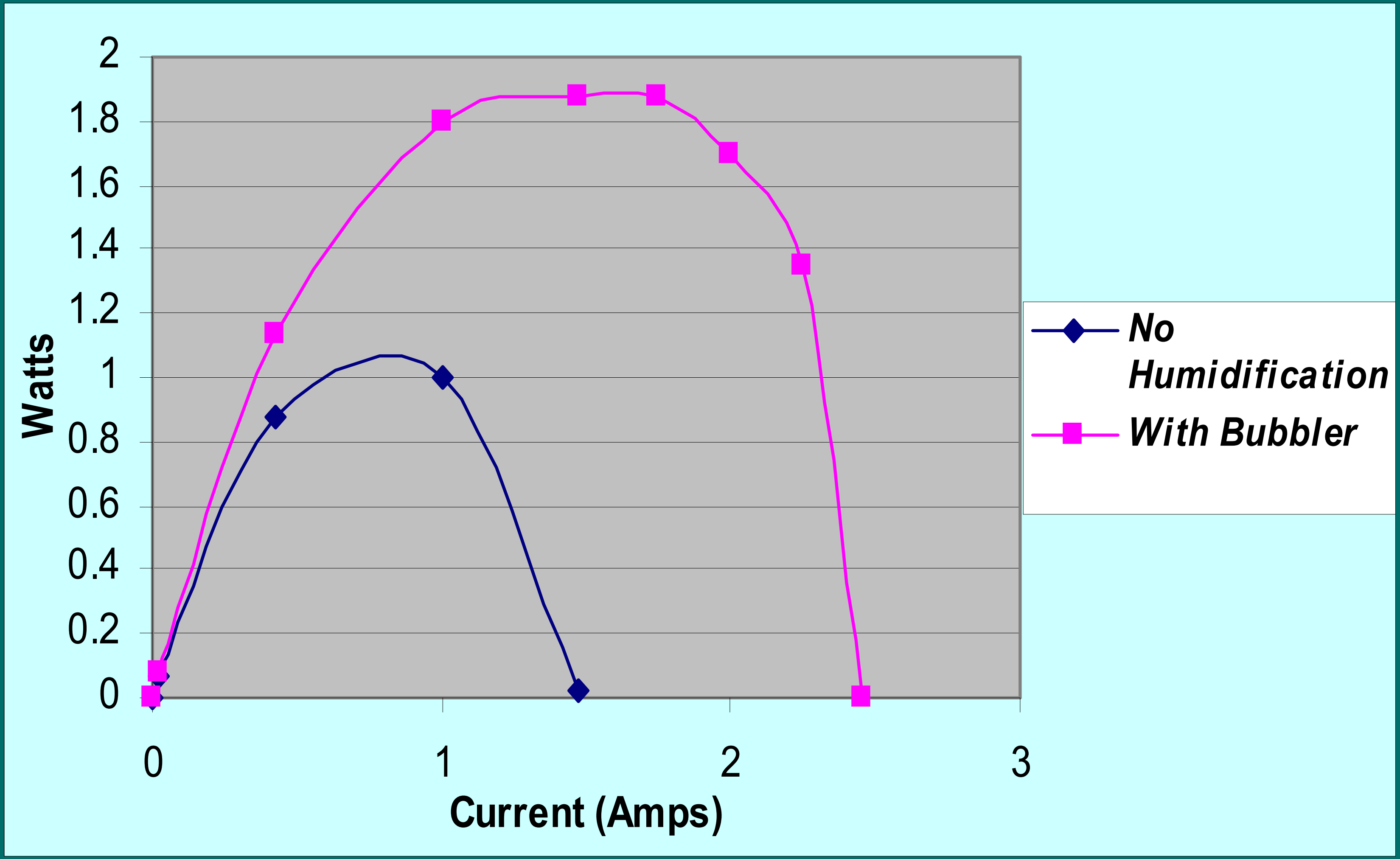
Effect of cell temperature on the polarization curve



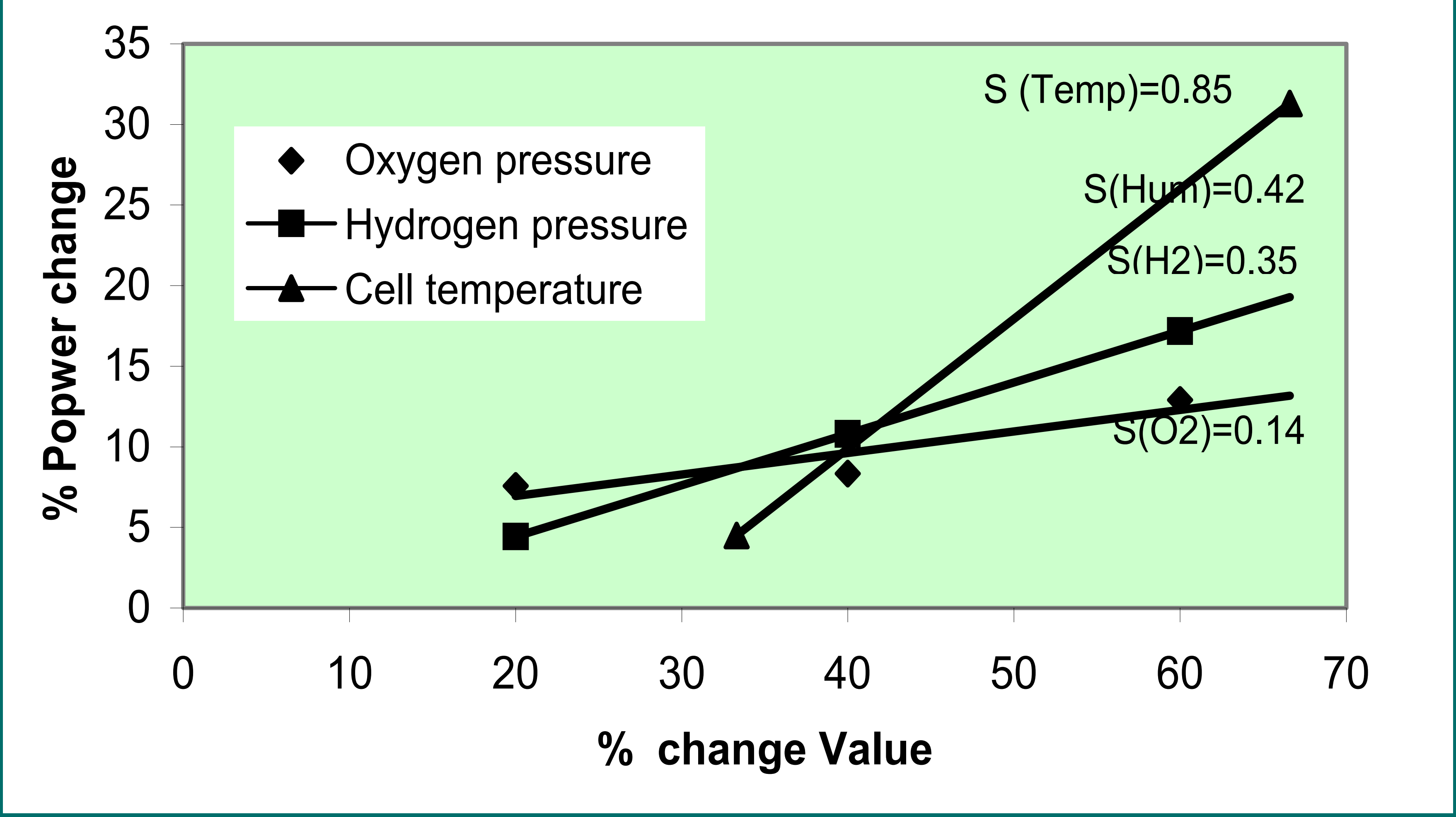
Effect of Cell Temperature on Power



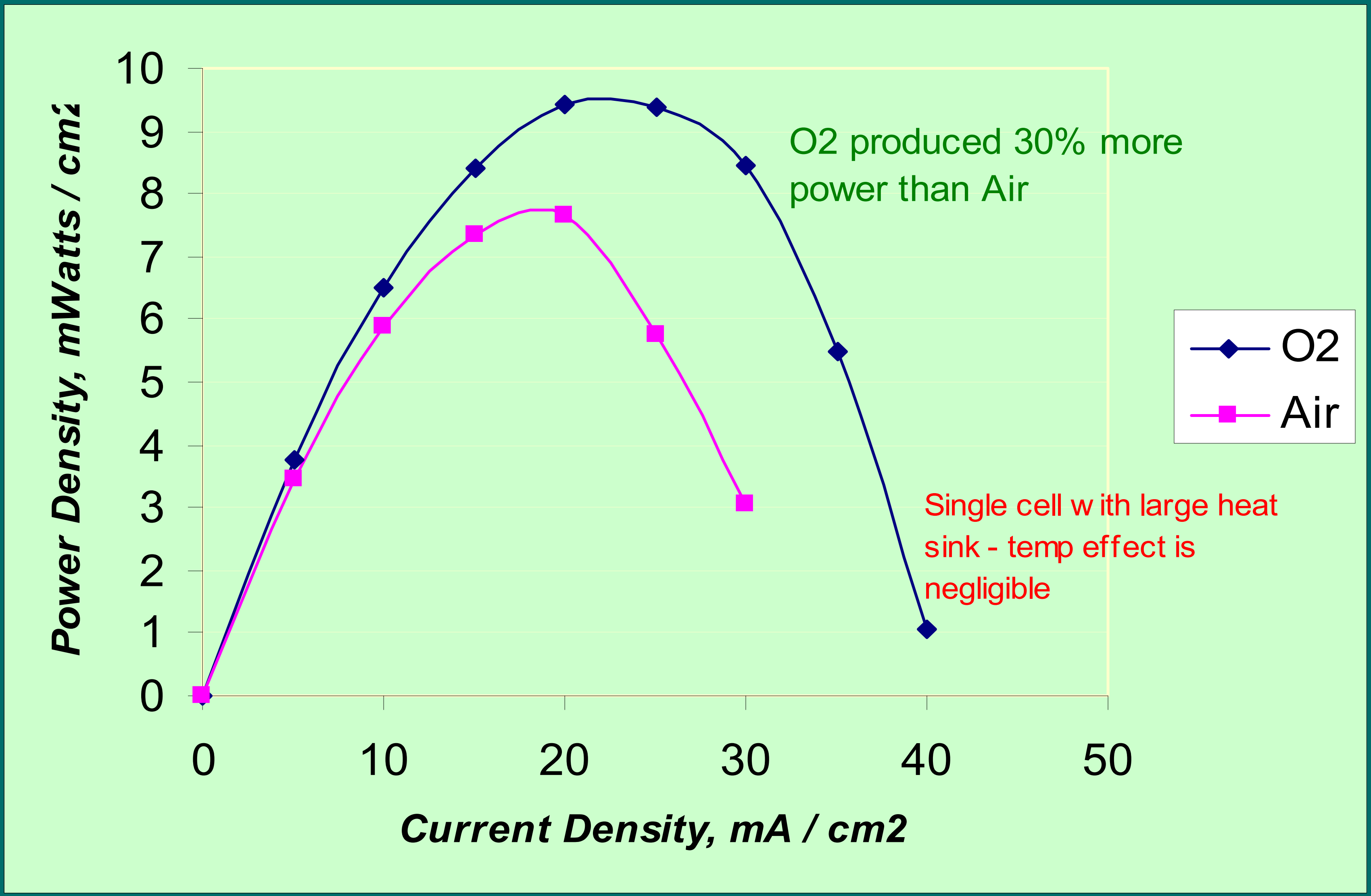
Humidity Effect at Room Temp



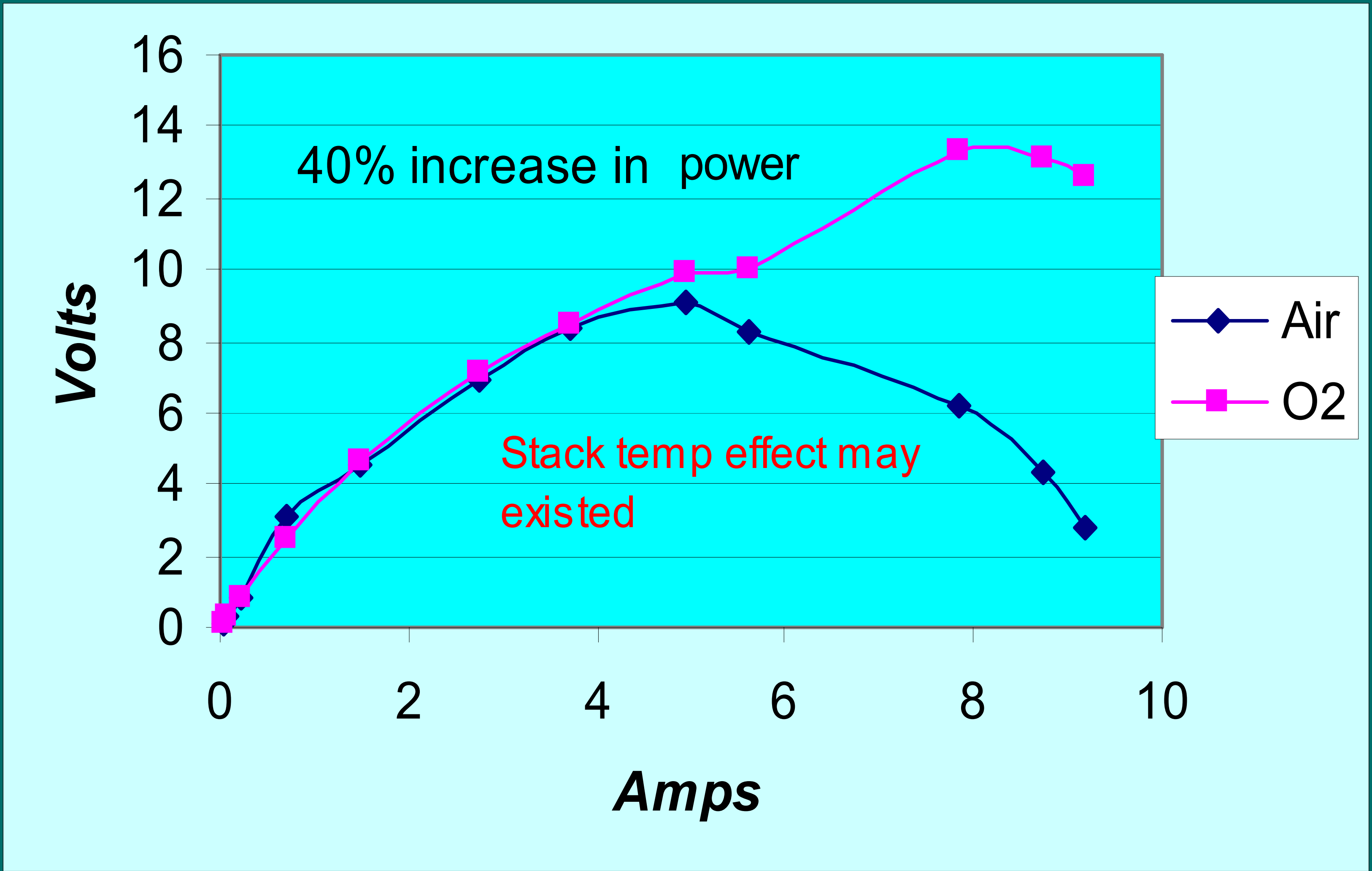
Cell temperature has the most significant effect on fuel cell performance



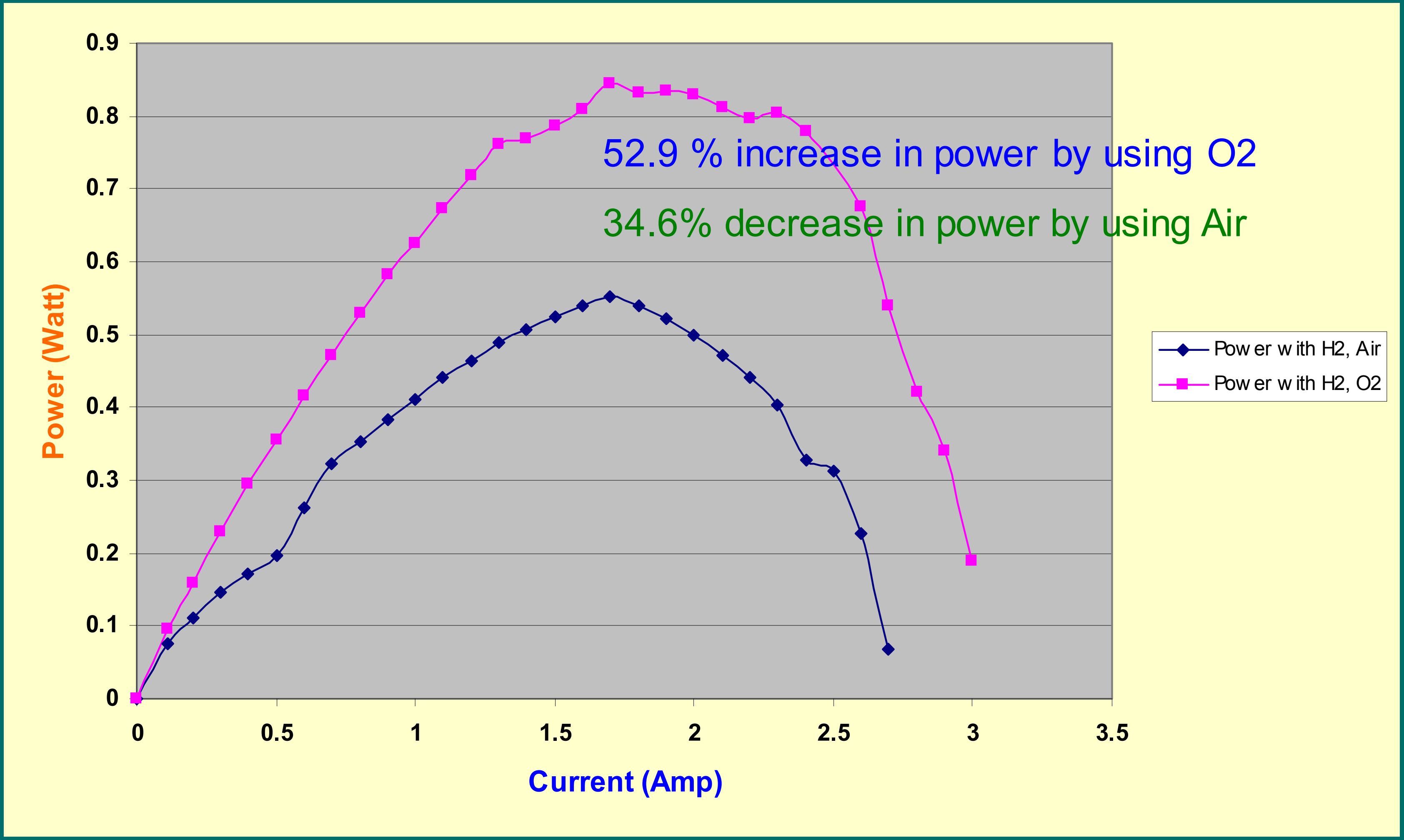
Air & O2 Effect on Power at Room Temp



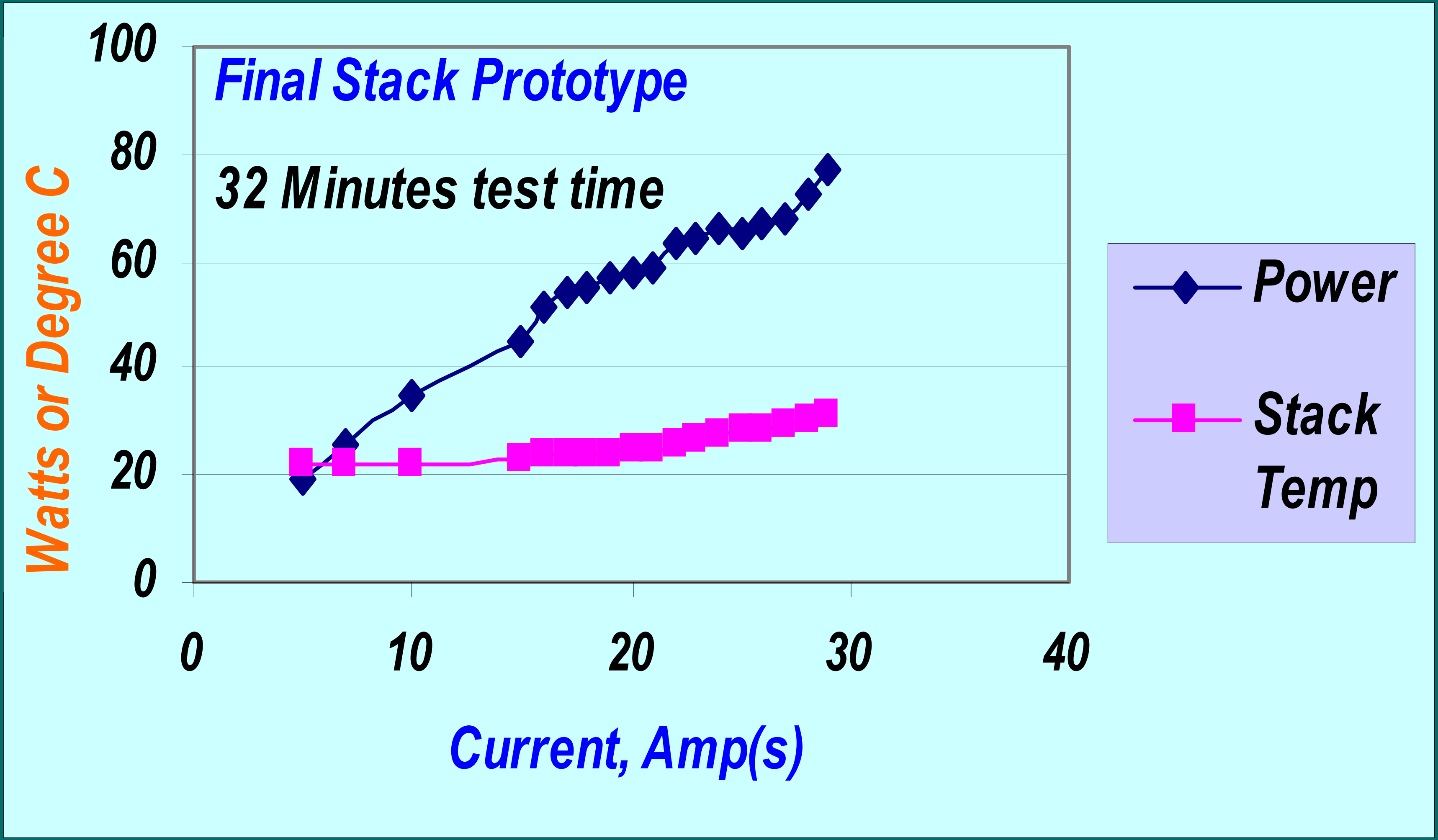
Effect of Air & O2 on Power



Effect of Air vs. O2 on FC Output

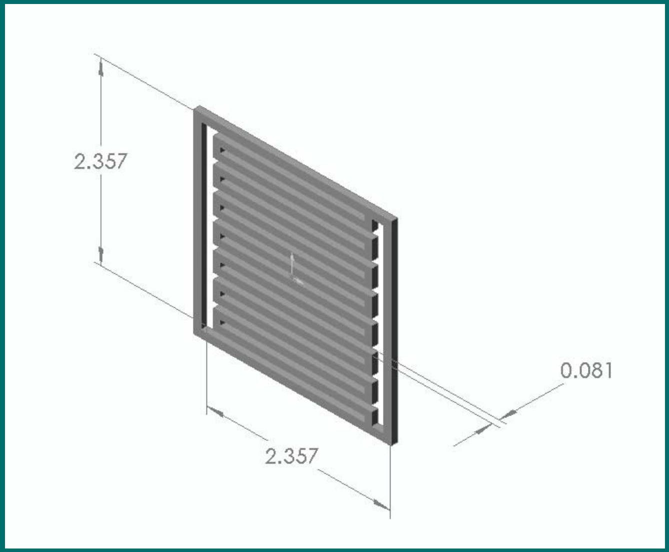


Performance Testing of the Final Stack Prototype

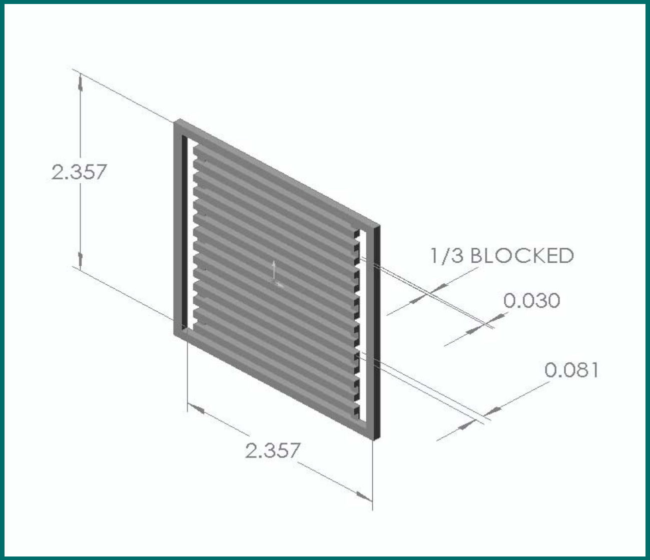


Interdigitated Flow Field Design

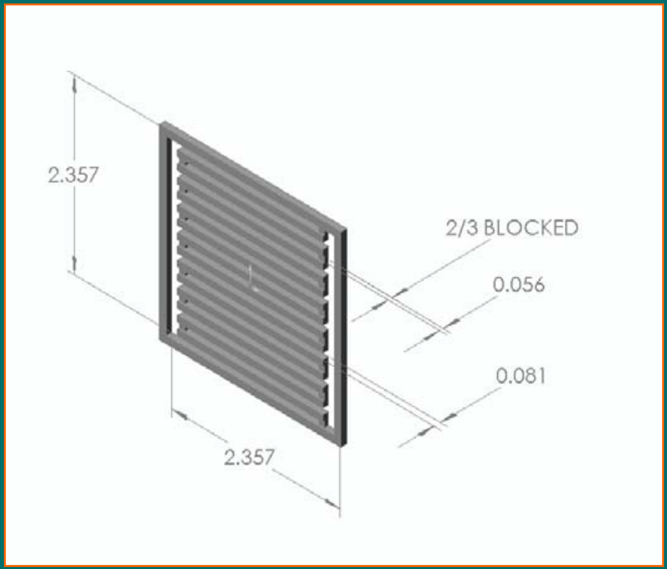
- Plate Design and optimization of Interdigitated flow fields – To enhance and change the interaction mechanism between reactant gases, electrolyte, and catalyst from diffusion to convective.



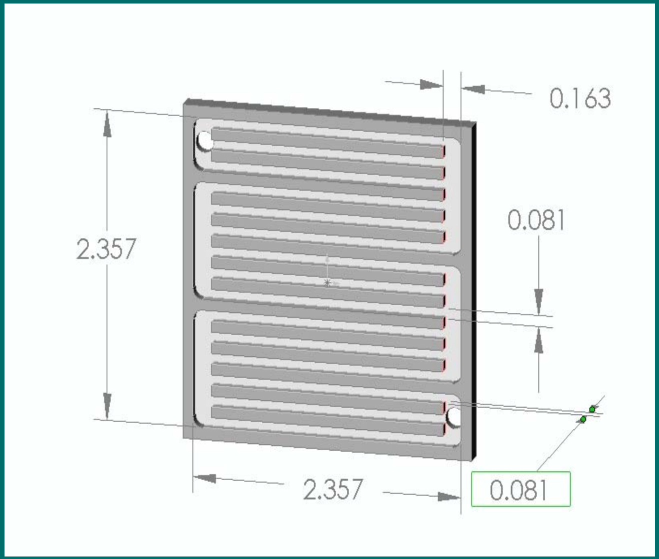
Fully Interdigitated



1/3 Interdigitated

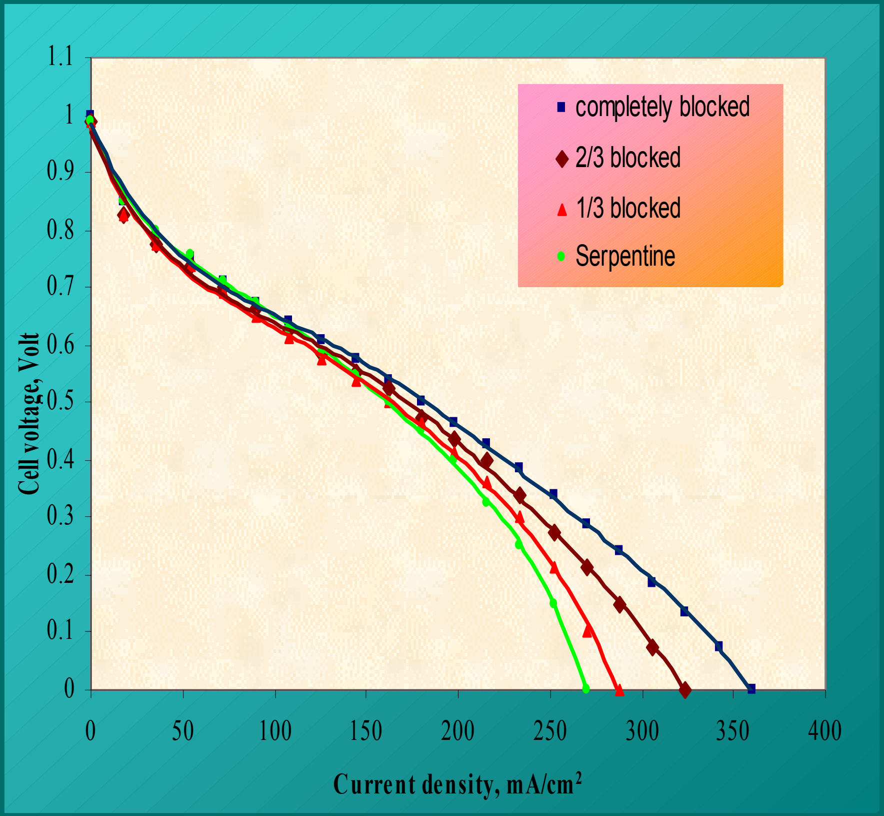


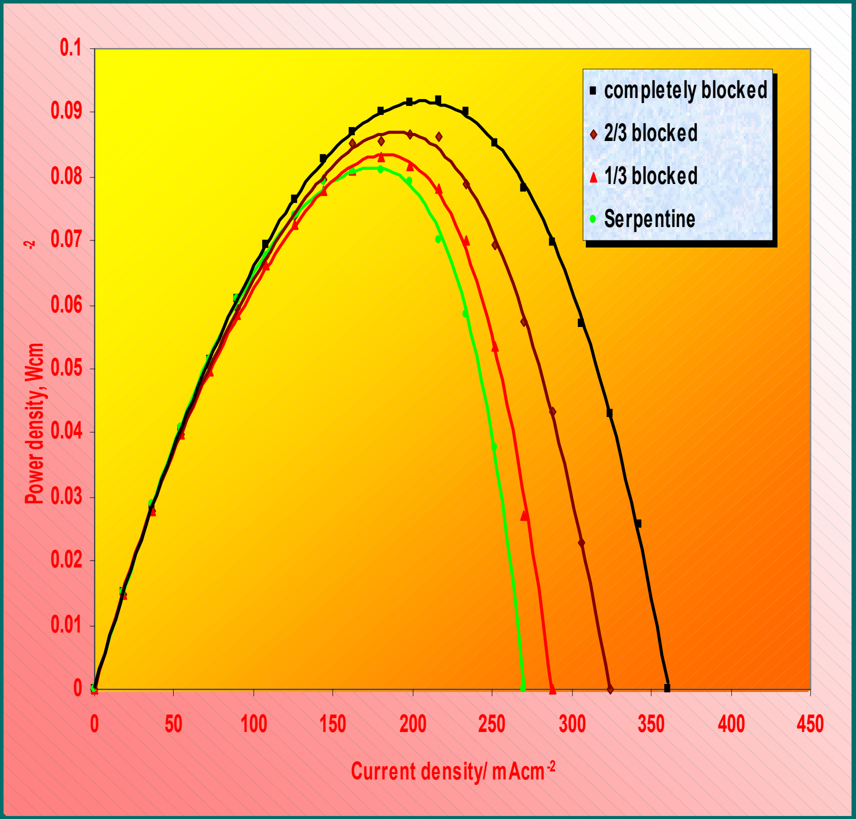
2/3 Interdigitated



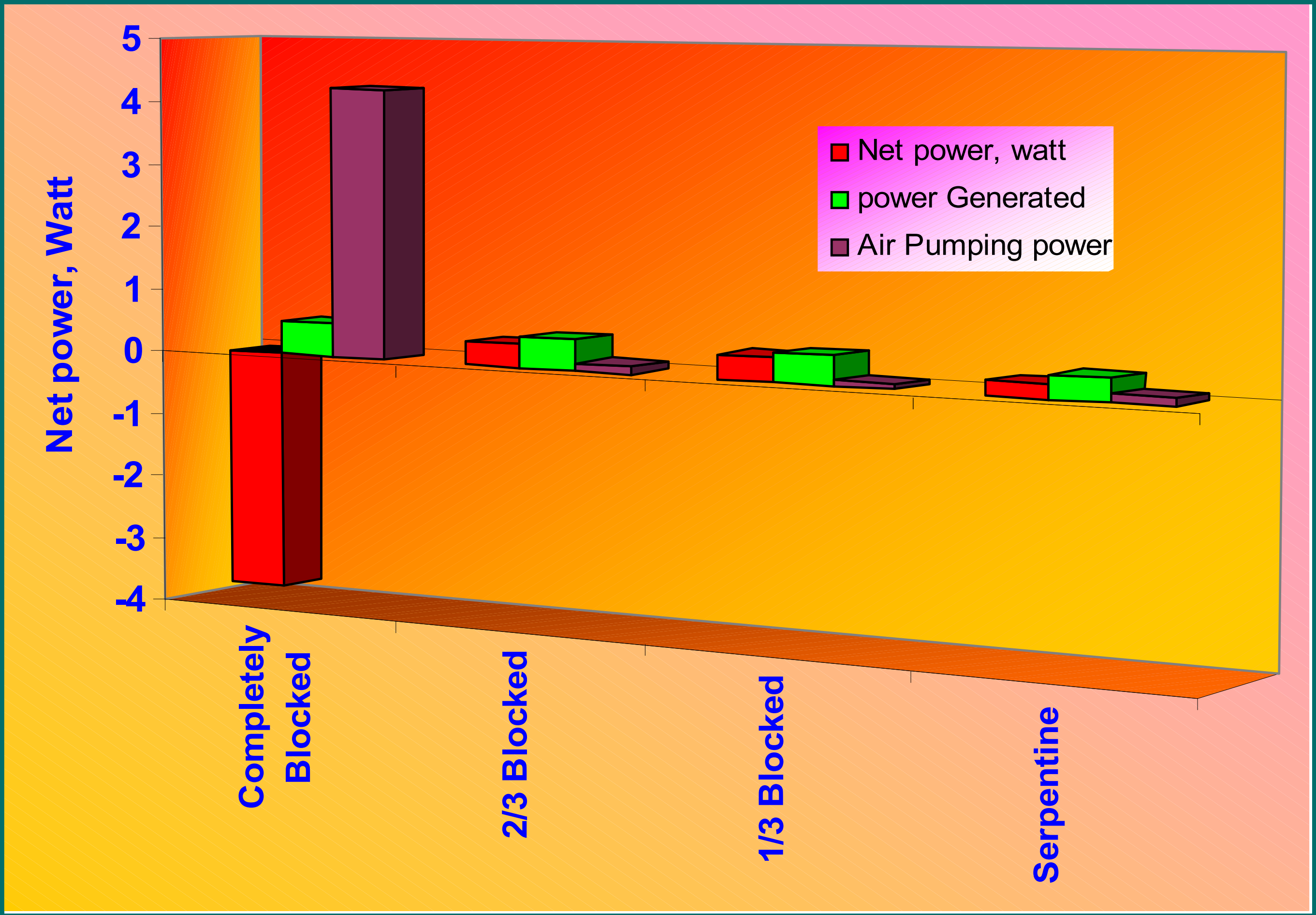
Regular Serpentine

Effect of Flow Field Interdigitated design on the Performance of PEMFC





Effect of Flow Field Interdigitated design on Net Power OF PEMFC



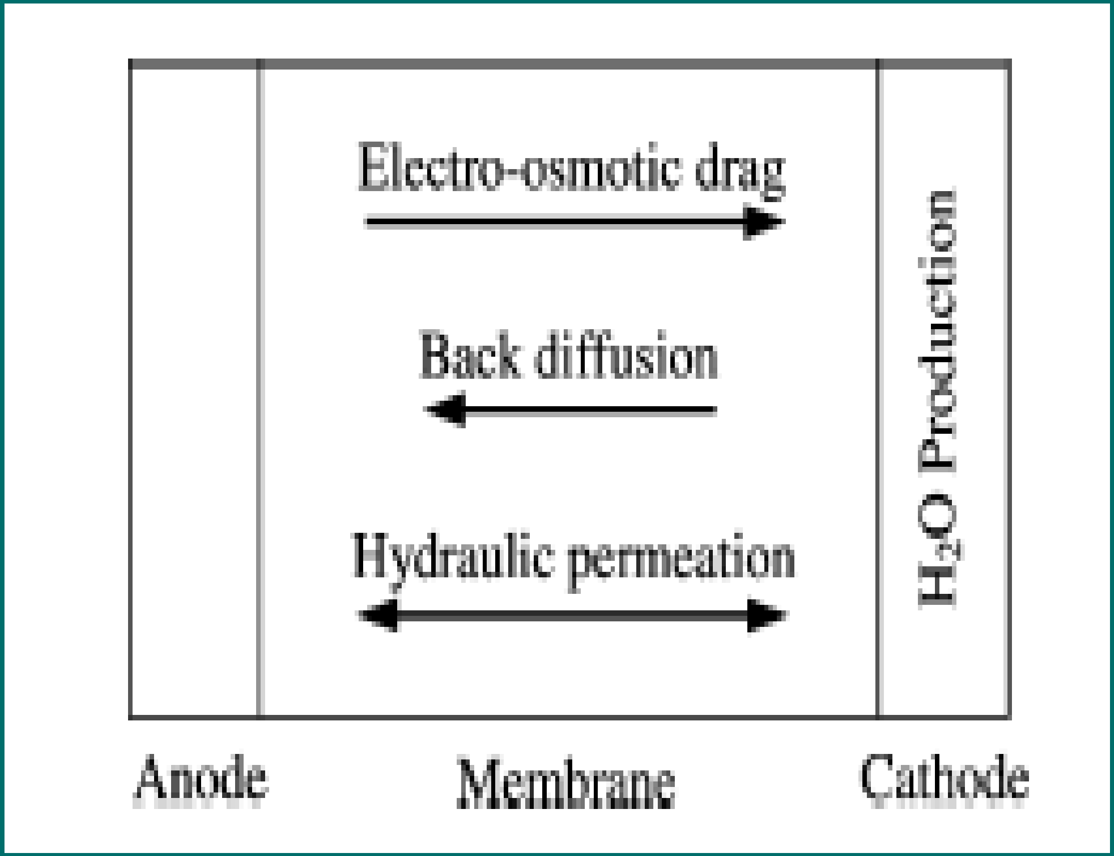
Design of Interdigitated Flow Field

- Changes the diffusion mechanism to a more effective connective flow field
- Uniform pressure distribution is necessary to produce uniform power density across the plate
- Uniform pressure distribution is necessary to avoid hot spots and crossover of reactants
- Crossover causes sever damage to MEA
- Computer simulation using STAR CD to generate uniform flow fields
- Interdigitation does improve power density

Water Management

- Is very crucial to the PEM Fuel Cell performance
- Dry out and flooding are very detrimental to the PEM performance
- Humidity must be kept around 90% R.H. inside the PEM fuel cell
- Efficient serpentine design was developed at IRTT/Farmingdale to minimize or eliminate the need for external humidification and allows the use of dry gases (Air & Hydrogen)

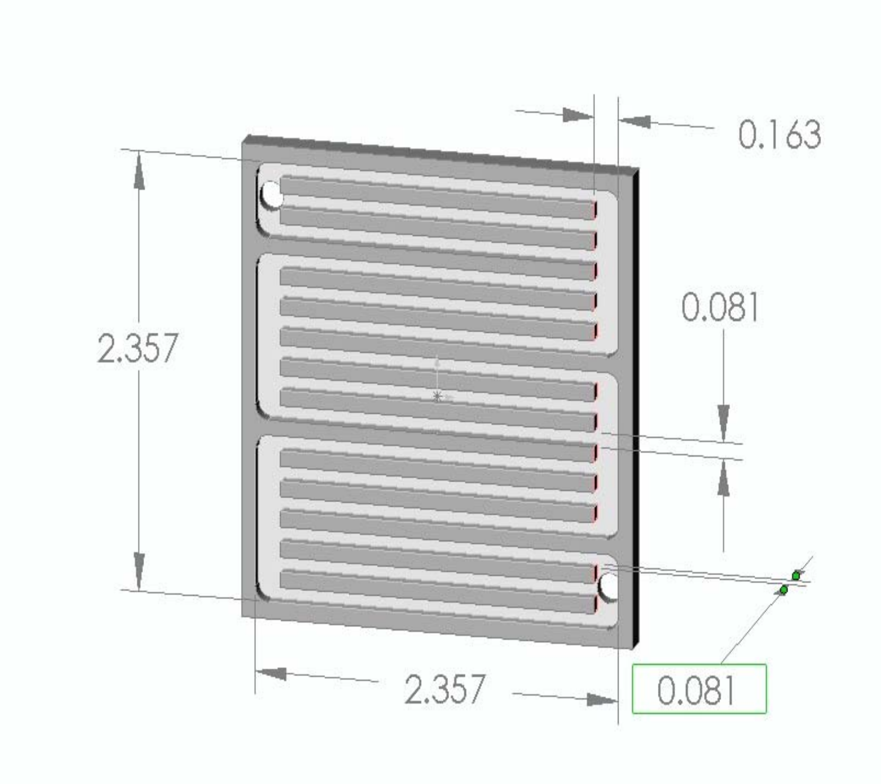
Water Transfer Mechanisms Across the MEA



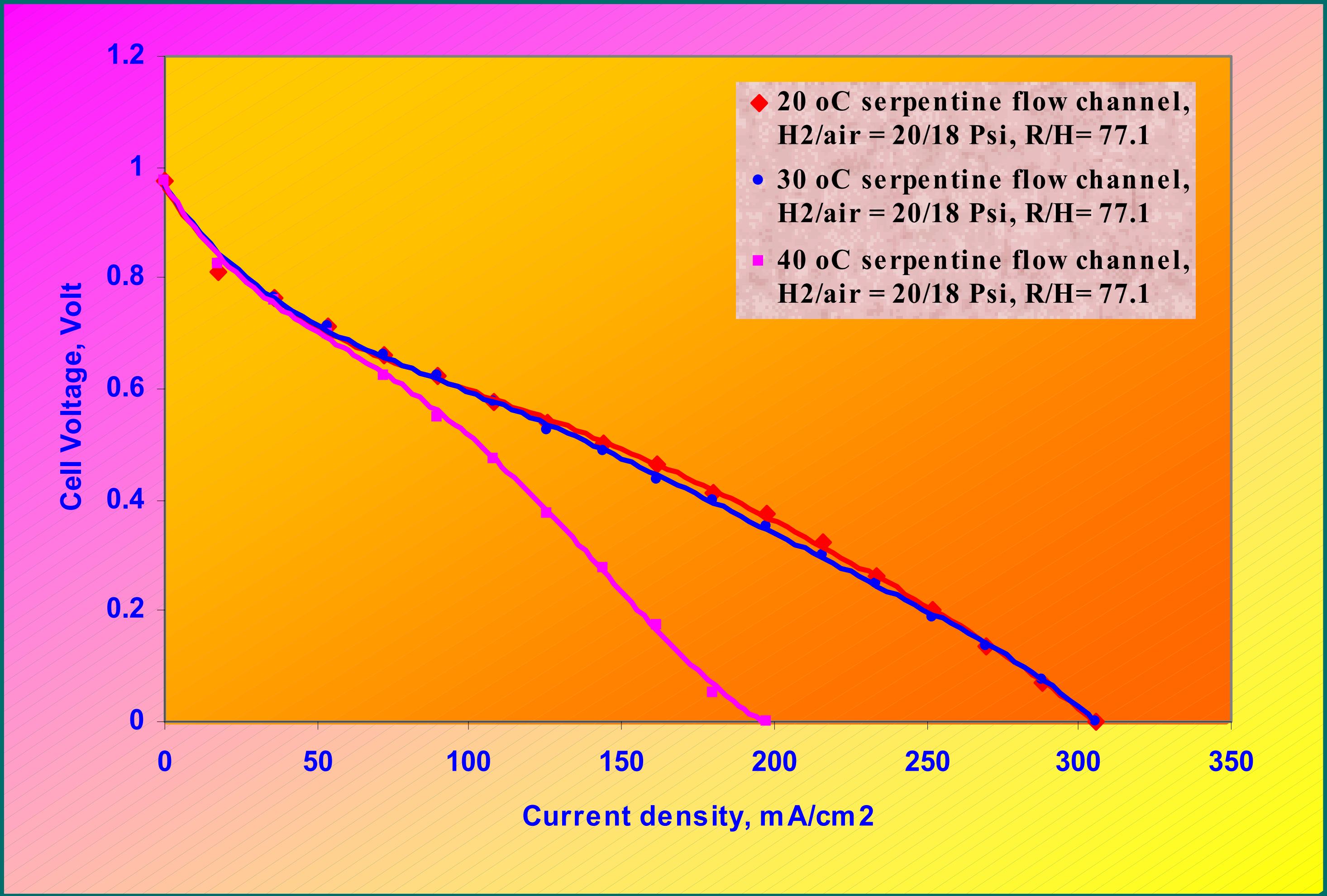
Flow Field Design Requirements

- **Plate design must allow for water/humidity conservation inside the power stack**
- **Common straight serpentine plate design does not allow for humidity conservation**
- **IRTT/Farmingdale developed two Flow Fields that allow for dry gases operating at 70 Degree C without any Dry out**

Common Serpentine Design



- **Straight Serpentine – requires external humidification**

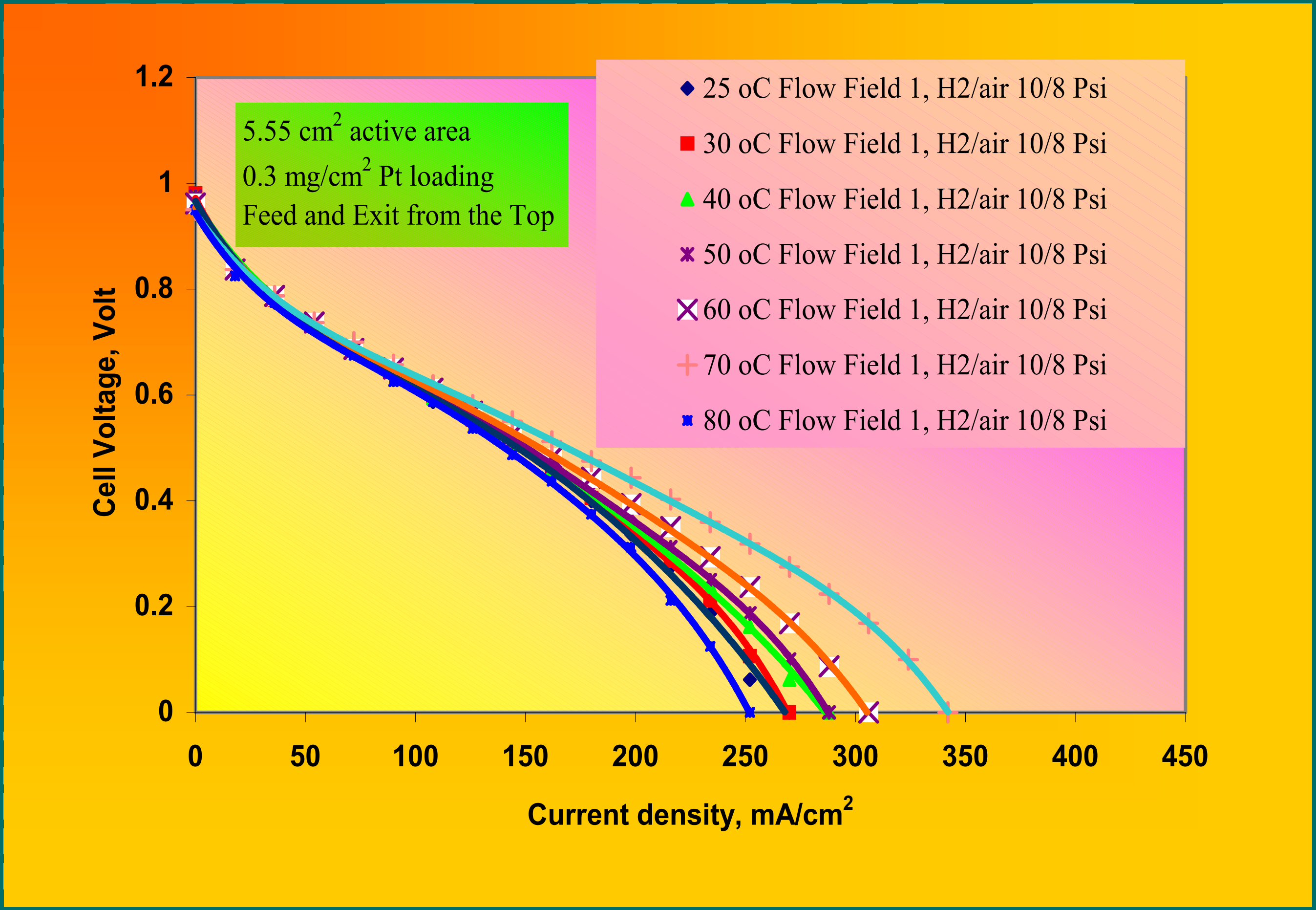


- Straight Serpentine – requires external humidification

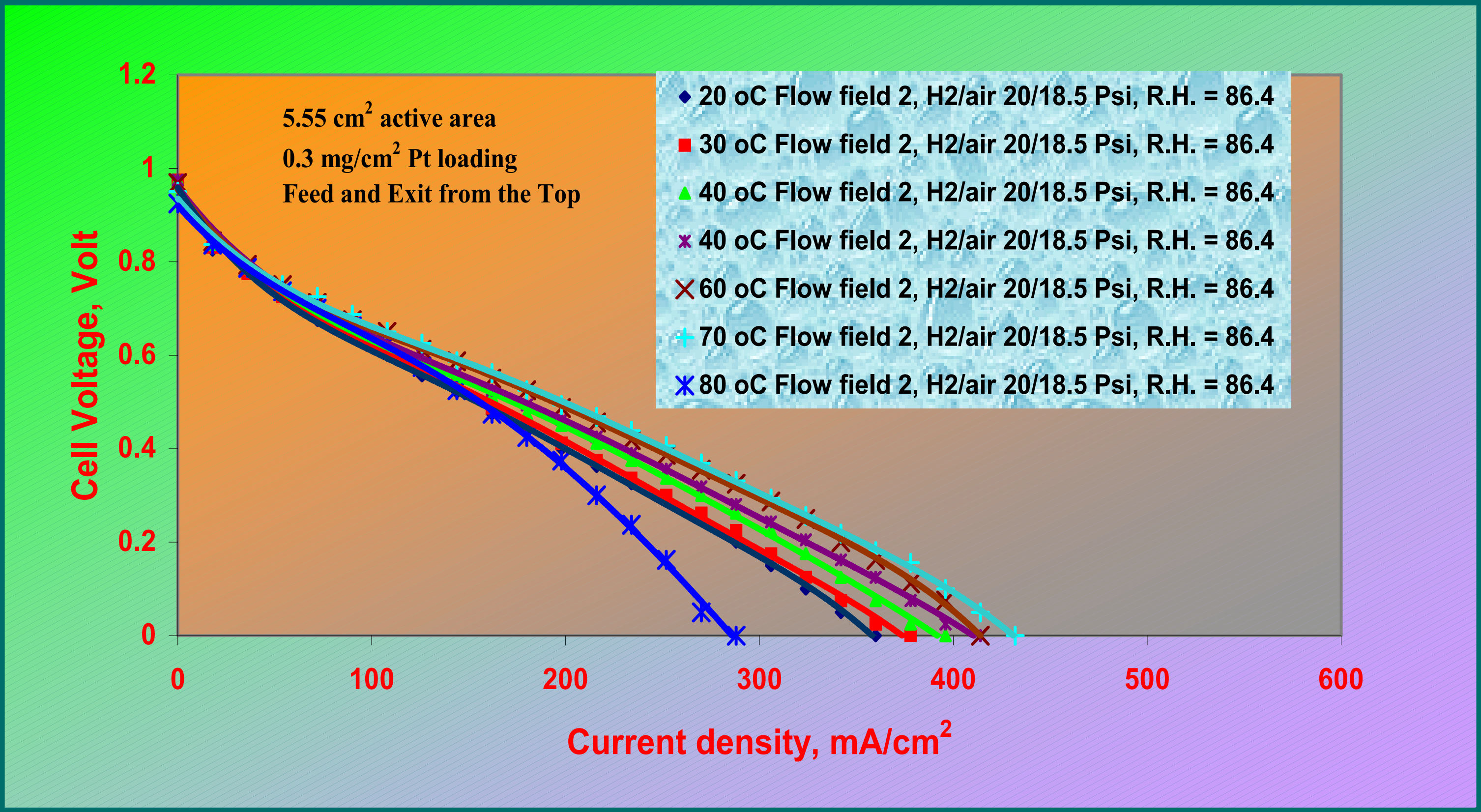
IRTT New Serpentine Design

Flow Field 1

Flow Field 2

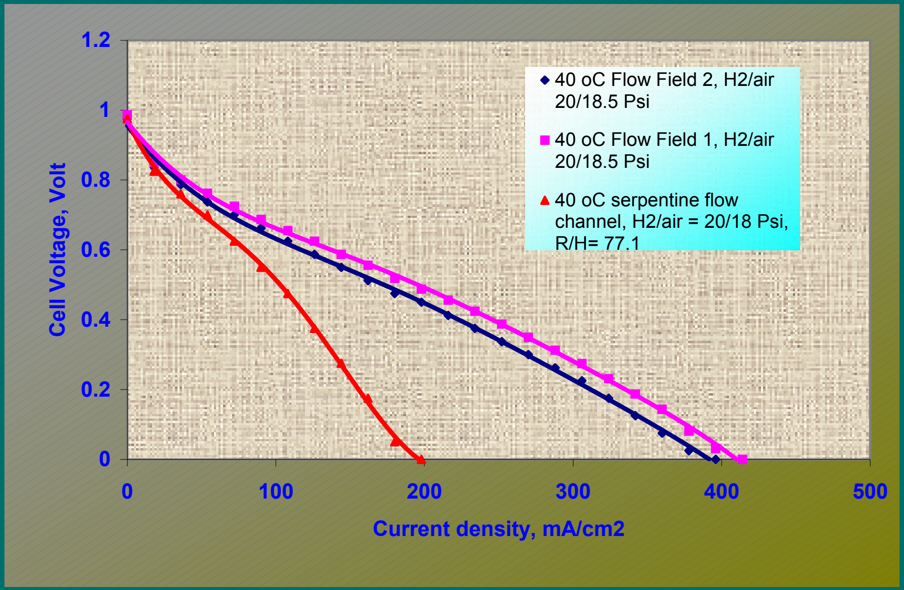


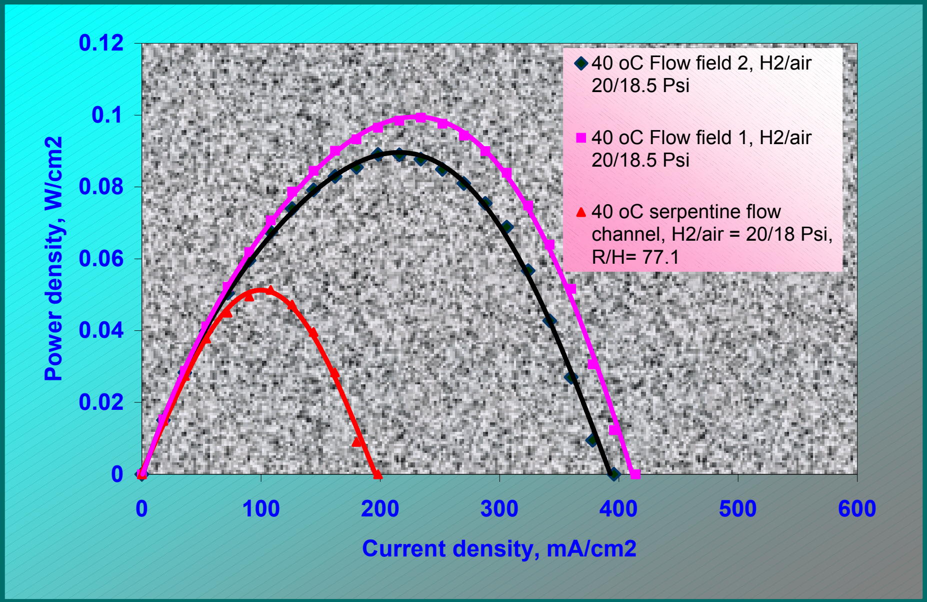
Flow Field 1– No External humidification is required



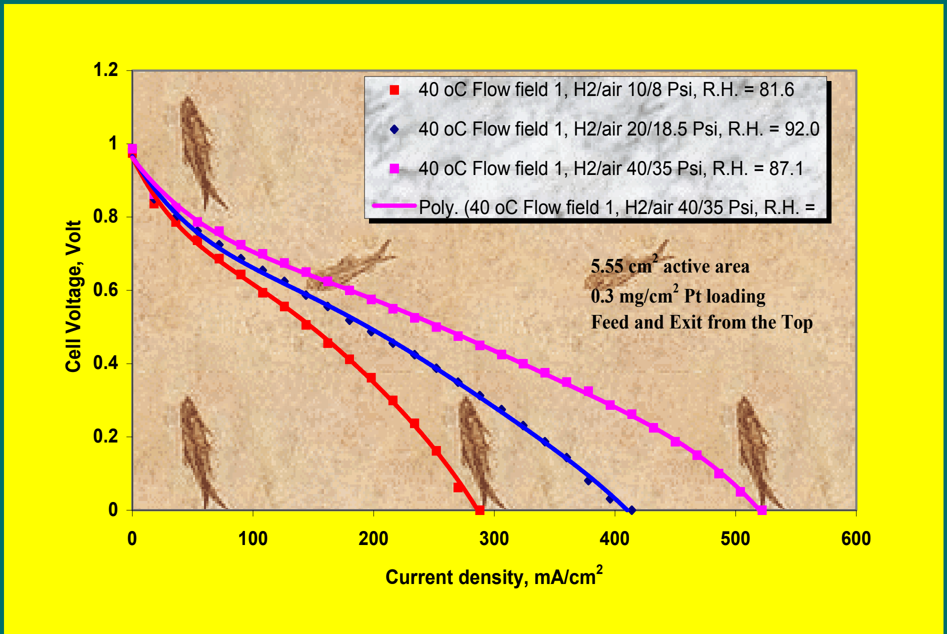
Flow Field 2 – No External humidification is required

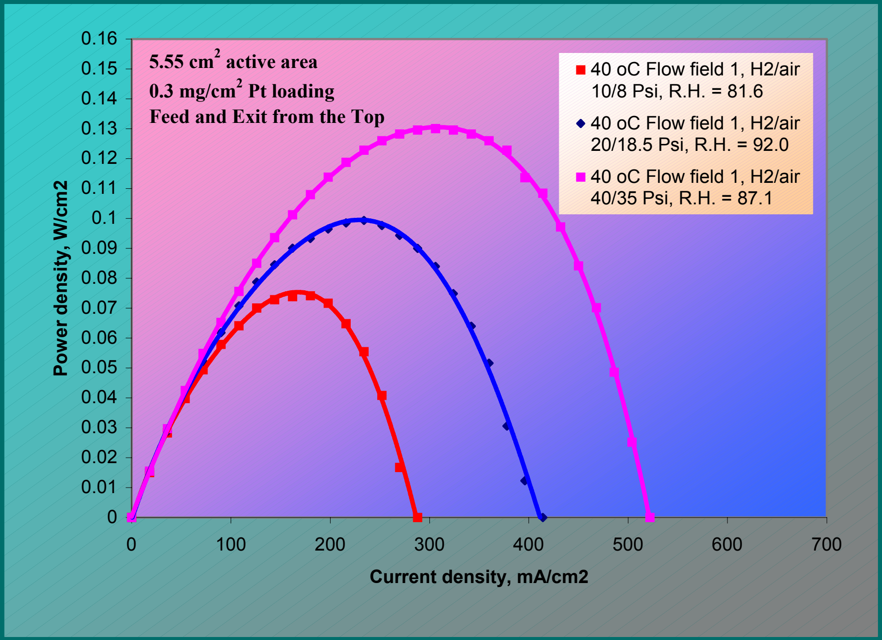
New flow field 2 design showed the best performance at 40 degree C





Effect of Hydrogen Pressure and Air Back Pressure on PEM Fuel Cell Performance





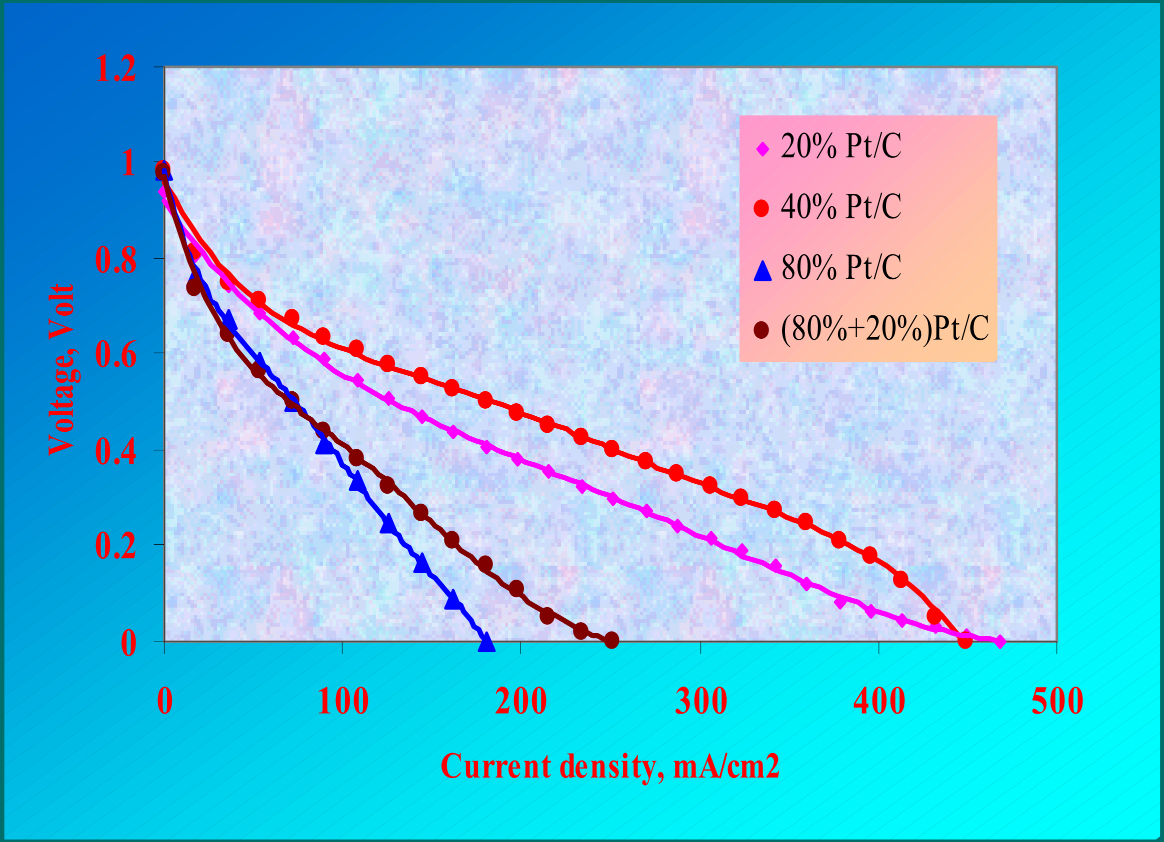
IRTT/ New MEA Technology

- Front Loading of High Concentration Supported Catalyst at the Nafion interface
- Increase the tri-interface between Catalyst, Electrolyte, and Reactant Gases

This results in the following:

- Low cost MEA
- High efficiency
- Cost effective MEA design with front catalyst loading
- Unsupported catalyst optimization

Cost Effective Technique of Front Catalyst Loading



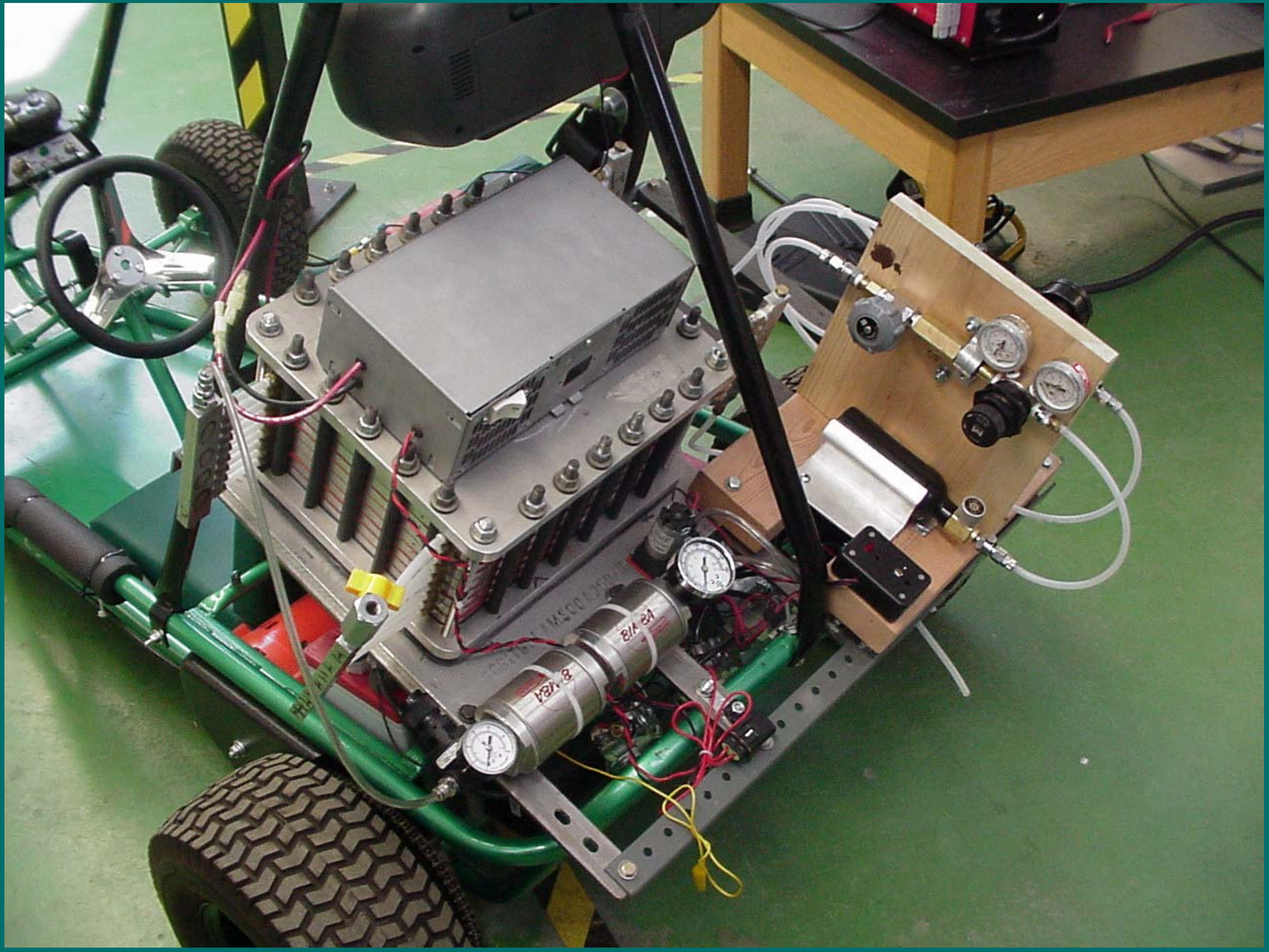
- **Pronounced effect of high catalyst concentration in the micro layer adjacent to the thin film Nafion interface**

Fuel Cell Applications:

- Small hybrid fuel cell/ battery pack powered vehicles
- Provide green power to residential homes using “net metering”

Hybrid Fuel Cell Battery Pack - Powering a Go Cart

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




NO PARKING ANY TIME
ELECTRIC POWERED
ELECTRIC POWERED
L 76589

Conclusions

- The world has moved from the steam economy to the ICE economy and is starting the new era of the hydrogen economy
- Fuel Cells powered by hydrogen produce clean & environmentally friendly energy and are receiving considerable attention from the U.S. government.
- Aluminum bipolar plates are proven to have very good performance and longevity.

Conclusions (Continue)

- Robust, efficient, and safe aluminum stack design has been achieved by IRTT with no crossover or outside leak of reactant gases
- Aluminum bipolar plates have excellent economic potential with 12% better hydrogen consumption than graphite
- IRTT has the experience, equipment, and instrumentation to fabricate, assemble, and test metal and/or graphite FC stacks.

Conclusions (Continue)

- **Three patent bending were filed by IRTT on the design and manufacturing of light weigh, corrosion resistance PEM metal power stacks**

- **IRTT's PEM Technologies are Ready to be Transferred and licensed to industry and Benefit the Local and National Market Economies**

Conclusions (Continue)

- Temperature and Humidity has the most significant influence on the FC power output and must be optimized
- We are very excited about our newly developed technologies and intend to continue moving forward

Proposals for Future PEM Development under the Hydrogen Institute in cooperation with Industry

Important Areas for PEM Development :

- Membraneless Fuel Cells - $ 285,000
- Test Metal Bipolar Plates at Higher Temp. 70^{o}C - $65,000
- Interdigitated Flow Field - $145,000
- Water Management using new Serpentine Design for Dry Reactant Gases $ 175,000
- MEA Cost Effective Studies for Supported and Unsupported Catalyst Loading - $150,000
- Hydrogen and Air Pressure and Temperature optimization - $145,000
- PEM Cost Reduction Studies – $125,000
- Fuel Cell Powered Vehicle - $ 150,000