PROSPECTS, CHALLENGES AND IMPEDIMENTS IN THE DEVELOPMENT OF BIOMASS GAS BASED SOLID OXIDE FUEL CELL (SOFC) IN INDIA

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Seminar on Challenges in Fuel cell Technology: India's Perspective
Indian Institute of Technology- Delhi
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Contents of the Lecture

What is a fuel cell?

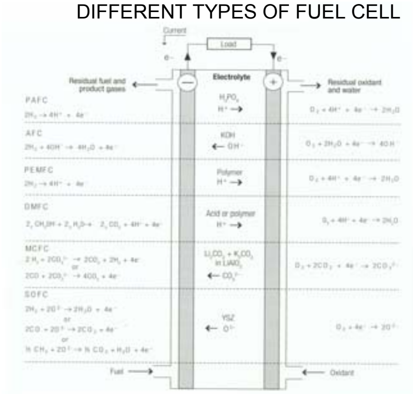
- **A fuel cell is an electrochemical device that combines hydrogen or other fuels and oxygen to produce electricity, with water and heat as its by-product. As long as fuel is supplied, the fuel cell will continue to generate power. Since the conversion of the fuel to energy takes place via an electrochemical process, not combustion, the process is clean, quiet and highly efficient – two to three times more efficient than fuel burning.**
- **No other energy generation technology offers the combination of benefits that fuel cells do. In addition to low or zero emissions, benefits include high efficiency and reliability, multi-fuel capability, Operation flexibility, durability, and ease of maintenance. Fuel cells are also scalable and can be stacked until the desired power output is reached. Since fuel cells operate silently, they reduce noise pollution as well as air pollution and the waste heat from a fuel cell can be used to provide hot water or space heating for a home or office.**

Types of Fuel Cells

Fuel Cell Designation		Electrolyte	Temperature °C	Cell Efficiency (Load Partial Load)	Type of Application
Alkaline Fuel Cell	AFC	Aqueous KOH	60.. .90	50.. .60	Mobile, stationary
Polymer Electrolyte Fuel Cell	PEFC	Polymer electrolyte Membrane	50.. .80	50.. .60	Mobile, stationary
Direct Methanol Fuel Cell	DMFC		110.. .130	30.. .40	Mobile
Phosphoric Acid Fuel Cell	PAFC	H_3PO_4	160.. .220	55	Stationary
Molten Carbonate Fuel Cell	MCFC	Alkaline carbonates	620.. .660	60...65	Stationary
Solid Oxide Fuel Cell	SOFC	ZrO2	800.. .1000	55.. .65	Stationary

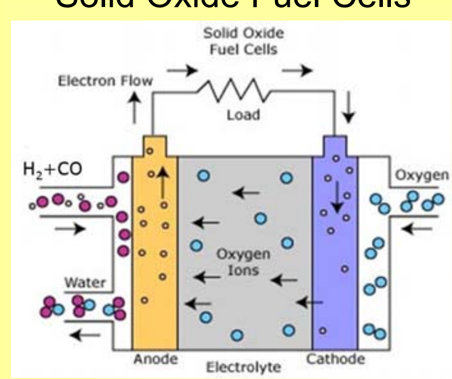
Reference : Automotive handbook – MICO

ELECTROCHEMICAL REACTIONS OCCURRING IN DIFFERENT TYPES OF FUEL CELL

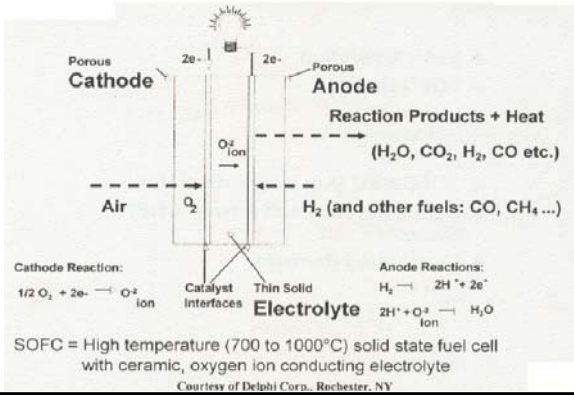


Taken from R.M.Dell and D.A.J.Rand, clean energy, the Royal Society of Chemistry, UK,2004

Solid Oxide Fuel Cells



Reactions in Solid Oxide Fuel Cell



Types of SOFCs

- Tubular
  - Extremely expensive production
  - Low power density
- Planar
  - High power density
  - Lends itself to mass production

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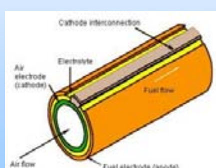
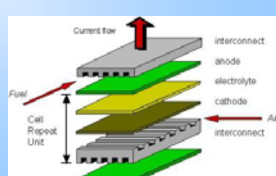




SOFC Advantages and Limitations

- **Advantages**
  - Being operated at high temperatures and cooling is done by air, there is no water management problem.
  - Can handle many conventional fuels, CO is also a fuel, and is more tolerant to higher concentrations of hydrocarbons and sulfur than for the PEMFC.
  - Considerably less complex fuel reforming compared to PEMFC. Particularly, natural gas fuel can be reformed within the stack,
  - With cogeneration, the system efficiencies can be quite high and flat over the operating temperature range.
  - Very low level of NOx and SO_X emissions.
  - Pressurized SOFC can replace the combustor in a gas turbine power plant to reach the efficiencies up to 70%.
- **Limitations**
  - High operating temperatures mean it requires special materials tolerant to those temperatures.
  - Sealing and thermal cycling are major problems.
  - Longer start-up time.

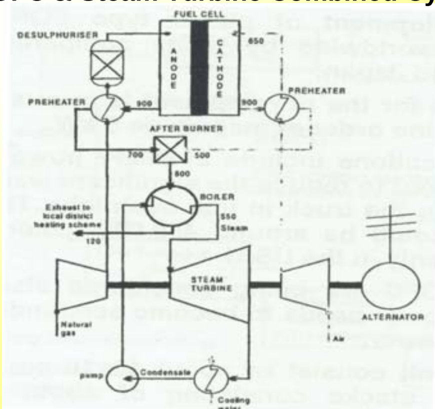
Application of Solid Oxide Fuel cell

- The development of planar type SOFC is being pursued worldwide by many companies in USA, Europe and Japan.
- The focus for the development Is in auxiliary power supply of the order of magnitude 5 kW.
- The applications include auxiliary power for trucks when parked to reduce the significant waste of diesel by running the truck in idle overnight. The expected savings could be around 450,000 gallons of diesel annually only in the USA!
- Planar SOFC are being considered also for home electric power needs to become semi-independent of the grid power.
- Typical unit consist of about 10x10 cm size plates with two stacks consisting of about 40-50 cells connected in series.

Combined Heat and Power (CHP) systems

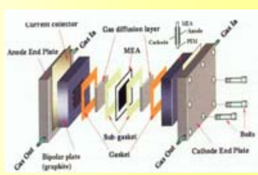
- The Siemens-Westinghpuse's SOFC power system has shown 46% electric efficiencies in pilot power plant. Small tube bundles have operated over 40,000 hours and a record 69,000 hours for a single tube SOFC.
- Combined-cycle system in which the fuel cell replaces the burner in a gas turbine cycle could achieve the overall system efficiency of over 70%.
- The high temperature fuel cell thus can exceed the efficiencies achieved today by combined gas and steam turbine (60%).
- The high temperature fuel cell can also tolerate many fuels and fuel impurities.
- For small-scale CHP technology (~100 kW to several MW), all fuel cell systems can be used.

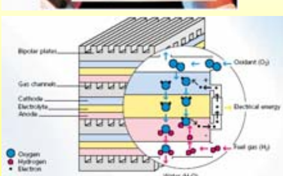
SOFC & Steam Turbine Combined Cycle



MANUFACTURING TECHNIQUES FOLLOWED FOR SOFC

SOFC Single Cell and Stack Arrangement





Important components and Requirements

Cathodes	**Improved Performance** • Improved Microstructure • Reaction Mechanisms • Component interconnections • Mixed Conductivity • Cost
Anodes	**Oxygen, Sulfur and Carbon Tolerance** ♦ Re- oxidation when exposed to Air ♦ Sulfur tolerance ♦ Carbon tolerance ♦ Internal reforming ♦ Cost

Important components and Requirements- Cont.

Electrolytes	**The function of electrolyte is to separate the two gas atmospheres and to transport the oxygen ions without significant losses from the cathode to the anode.** ♦ It should have sufficient oxygen ion conductivity ♦ Minimum voltage loss across the electrolyte ♦ Stable under oxidizing condition ♦ Should have sufficient mechanical strength ♦ Yttria stabilized Zirconia (ysz) is extensively used ♦ Alternate electrolyte materials are perovskitiees based on $LaGaO_3$ doped with ceria. ♦ Should be chemically stable in large oxygen partial pressure gradient potential

Important components and Requirements - Cont.

Interconnects (Bipolar plates)	**The interconnect has to meet the following demands** ♦ High electronic and low ionic conductivities (electrical conductivity > 1 S cm^{-1}) ♦ Chemical stability under the reducing and oxidizing conditions at the anode and cathode sides of the cell at temperature of up to 1000C (Range of oxygen activity 10^{-18}-1 bar) ♦ Gas tightness; ♦ Thermal expansion coefficient matching with that of other cell components ♦ Low costs.
Seals	Leakage and Stress Hydrogen Leakage Rigidity of Stack Volatility and Stability of seal material Cost

Important components and Requirements - Cont.

Components for reactant supply and products outlet	For the supply of hydrogen and other fuels to the anode and oxygen/air to the cathode and to evacuate H_2O and CO_2 products 1. It should withstand hgh temperature oxidation / reduction reactions 2. Leak proof connection to the end plates
Instrumentation	1. To measure the temperature, pressure, voltage and current of the cells, intermediates and electrodes

Materials for SOFC applications

Electrolyte	YSZ, ScSZ, CeO_2 (mod.) $LaGaO_3$ (mod.)
Anode	Ni/YSZ, Ni/CeO_2 (mod). Cu/YSZ, Cu/CeO_2 /YSZ, Ni/$SrTi_{1-x}$ $Nb_{\sim 3}$, Ni/La_xSr_{1-x} TiO_3, Ni/Y,Zr, Ti)O_2, Ni/(Y,Sc,Zr,Ti)O_2, Ni/Sr_2Ga NbO_6
Anode substrate	Ni/YSZ, Ni/Al_2O_3, Ni/TiO_2, Ni/$NiCr_2O_4$
Cathode	(La, Sr, Ca)MnO_3, (La, Sr, Ca)CoO_3, (Pr,Sr,Ca)MnO_3, La(Sr,Ca)FeO_{-3}, La(Ni,Fe)O_3
Interconnect, Ceramic/metallic	$LaCrO_3$ (mod). Ferritic Steel Cr-based alloys, Austenitic steel
Sealing	Glass, Glass ceramic, Metallic gasket

CURRENT PROCESSING TECHNIQUES USED FOR SOFC

Extrusion (Cathode) → Drying, Sintering → Plasma spraying (Interconnect) → Sintering → Ni-dipping (Anode) → Electrochemical vapor deposition (Electrolyte) → Electrochemical reaction

a) the tubular design

Tape Casting (Electrolyte) → Sintering → Screen Printing (Anode, Cathode) → Co fining →

b) the electrolyte-supported design and

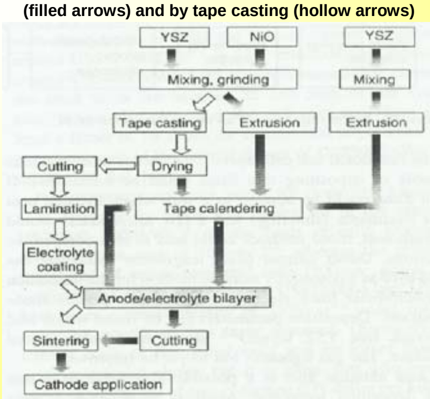
Tape Casting (Anode) → Pre – Sintering → Screen Printing (Electrolyte) → Sintering → Wet powder spraying (Cathode) → Sintering →

c) the anode-supported design

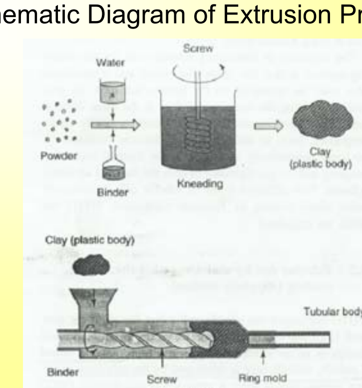
Processing / Fabrication Techniques used for Fuel Cell Elements

- **Siemens Westinghouse tubular design**
  - Cathode acts as substract / carrier
  - Electrolytes are deposited on the cathode followed by anode and
  - Interconnect is running along the length for distributing the reactants.
  - Tubular cell was originally made by vapor deposition. Number of layers are formed depending upon the requirement
- **Mitsubishi Heavy Industry**
  - Made the substrat by Plasma spray later switched over to sintering method to reduce the cost
  - Sintering method gives porous substrat giving problem in depositing interconnect films.
- **TOTO, Japan**
  - Followed slurry coating technique using $LaMnO_3$ Casting/ extrusion mould technique
  - The Electrodes are then coated by dipping process or by printing method

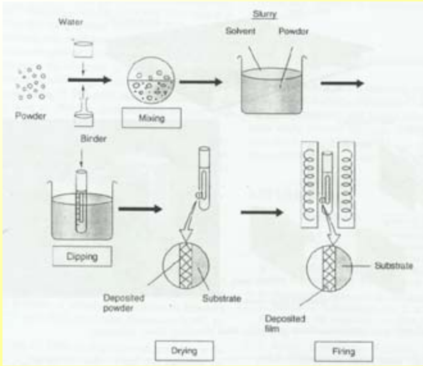
Processing scheme for SOFC fabrication by tape calendaring (filled arrows) and by tape casting (hollow arrows)



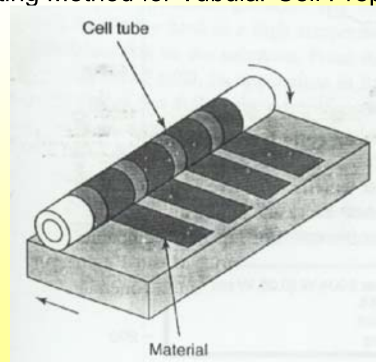
Schematic Diagram of Extrusion Process



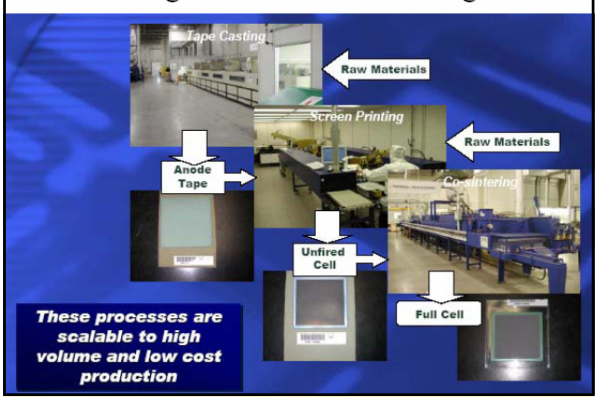
Schematic of the Slurry Coating (Dipping) Process.



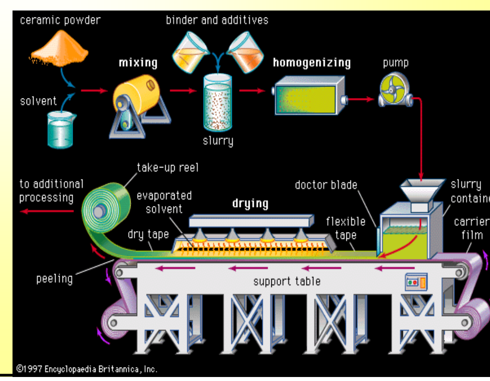
Printing Method for Tubular Cell Preparation



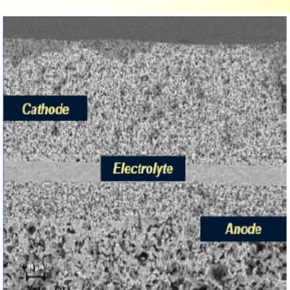
Single-Cell Manufacturing



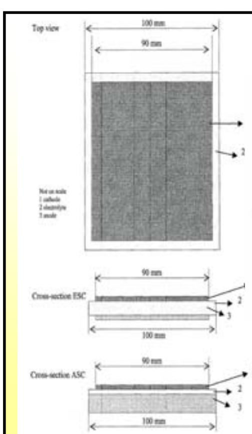
Tape casting of SOFC cell

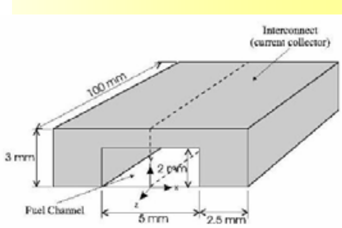


Planar SOFCs: Microstructure



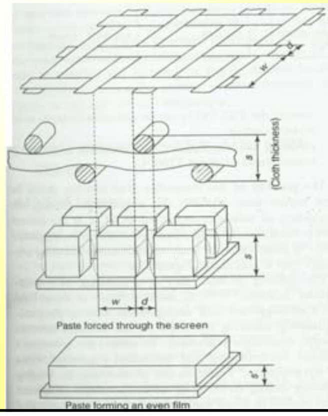
- *Anode* – nickel-zirconia cermet, ~ 1 mm thick
- *Electrolyte* – yttria-stabilized zirconia (YSZ), ~ 5 μm thick
- *Cathode* – conducting ceramic, ~ 50 μm thick



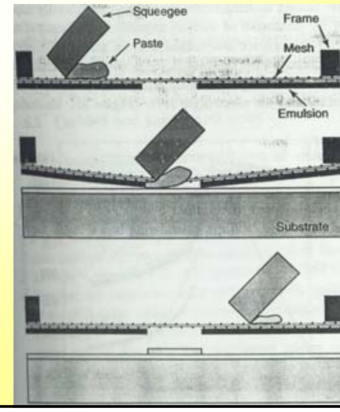


Schematic of the anode model domain

Correlation between screen and paste film on the substrate



SCREEN-PRINTING PROCESS



Details of the SOFC Project under progress in VIT

Project Funding Details

Project title	"Development of Technology for Upgradation of Producer Gas From Biomass Gasifier As Feed Stock In Solid Oxide Fuel For Power Generation"
Project funded by	Department of Science and Technology (DST)
Project No.	SR/S3/MERC/11/2005-SERC-Engg.
The total amount allocated for this project	Rs. 21,52,800 /-
	Rs. 17,94,000/-
For Institutional overheads	Rs. 3,58,800/-
Additional funding from VIT	**Rs. 10,00,000/-**
Duration of the Project	30 months

ORGANIZATIONS CONTACTED FOR THE SUPPLY OF SOFC ELEMENTS

FUEL CELL MANUFACTURERS	FUEL CELL	LOCATION	
Acumentrics Corporation (USA)	5 kW tubular SOFC beta unit	♦ Cleveland, Ohio. ♦ Japan ♦ Sheridan, Wyoming	♦ Seward, Alaska ♦ Houston, Texas ♦ Idaho Falls, Idaho
Ceramic Fuel Cells Ltd. (CFCL) Australia	1 kW Micro-CHP SOFC	♦ South Melbourne, Australia ♦ Chadstone, Australia ♦ Brandenburg, Germany	♦ State of Tasmania, New Zealand ♦ Wellington, New Zealand ♦ Oldenburg, Germany

ORGANIZATIONS CONTACTED FOR THE SUPPLY OF SOFC ELEMENTS

FUEL CELL MANUFACTURERS	FUEL CELL	LOCATION	
Fuel Cell Technologies (FCT) Canada	5 kW SOFC	♦Mississauga, Canada ♦Ft. Meade, Maryland ♦Kingston, Canada ♦Itajuba, Brazil ♦Vancouver, Canada ♦Pittsburgh, Pennsylvania ♦Liege, Belgium ♦Parker Dam State Park, Pennsylvania ♦Fairbanks, Alaska ♦Mechernich and Essen, Germany	♦Yokohama, Japan ♦Dearborn, Michigan ♦Vancouver, Canada ♦Kingston, Canada ♦Morgantown, West Virginia ♦Memphis, Tennessee ♦San Francisco, California ♦Stockholm, Sweden ♦Various locations, California
Global Thermoelectric USA	2 to 5 kW SOFC systems	♦Various locations, USA ♦Billings, Montana ♦Calgary,	
Minaton (Russian Ministry of Atom)	1 kW SOFC	♦Snezhinsk, Russia	

ORGANIZATIONS CONTACTED FOR THE SUPPLY OF SOFC ELEMENTS

FUEL CELL MANUFACTURERS	FUEL CELL	LOCATION	
Mitsubishi Heavy Industries (MHI), Japan	150-200 kW SOFC	♦ Japan	
Siemens Power Generation, Inc Germany	400W to 300 kW SOFC CHP	♦ Turin, Italy ♦ Alaska ♦ Hannover, Germany ♦ Sinetta Marengo, Italy ♦ Nikiski, Alaska ♦ Toronto, Canada ♦ Mississauga, Canada ♦ Bergen, Norway	♦ Essen, Germany ♦ Toronto, Canada ♦ Austria ♦ Irvine, California ♦ Irvine, California ♦ Westervoort, Netherlands; Essen, Germany ♦ Japan
Sulzer Hexis Switzerland	1 kW HXS 1000 Premiere	♦ Dresden, Germany ♦ Zurich, Switzerland ♦ Northwestern Switzerland ♦ La Plaine Saint-Denis, Paris, France ♦ Berlin-Buckow, Germany ♦ Gadebusch, Germany ♦ Barby, Germany ♦ Weimar, Germany ♦ Various locations, Germany	♦ North Rhine-Westphalia area, Germany ♦ Essen, Germany ♦ Attnang Puchheim, Austria ♦ Petten, Netherlands ♦ Lully, Switzerland ♦ Tokyo, Japan ♦ Groningen, Netherlands ♦ Bilbao, Spain ♦ Basel, Switzerland ♦ Winterthur, Switzerland

ORGANIZATIONS CONTACTED FOR THE SUPPLY OF SOFC ELEMENTS

FUEL CELL MANUFACTURERS	FUEL CELL	LOCATION
Tokyo Gas Japan	SOFC	♦ Japan
ZTEK Corp.USA	25 kW SOFC	♦ Rocky Hill, Connecticut ♦ Huntsville, Alabama ♦ Japan
International fuel cell USA	SOFC	♦ USA
Gesellschaft fur innovative Eenrgie und Wasserstoff-Technologie mbH (ET)	SOFC	♦ Brunnthal, Germany
Gastech Technology BV	SOFC	♦ Apeldoorn, Netherlands
Fuel Cell Institute of Australia Pty Ltd (FCIA)	SOFC	♦ Cabramatta NSW, Australia

ORGANIZATIONS CONTACTED FOR THE SUPPLY OF SOFC ELEMENTS

FUEL CELL MANUFACTURERS	FUEL CELL	LOCATION
Global Photonic Energy Corporation	SOFC	♦Ewing NJ, United States.
Electrochem, Inc.	SOFC	♦Woburn MA, United States
Electric Fuel Limited	SOFC	♦Beit Shemesh, Israel
Agni Energie Sdn Bhd	SOFC	♦Shah Alam, Malaysia
HT Ceramix	SOFC	♦Switcherland
InDEC	SOFC	♦Netherland

Firms responded for the supply of SOFCs and components

- HT Ceramix- Switcherland for the supply of 100W fuel cell stack with strict conditions
- Indec – Netherland for the supply of anode, and electrolyte fuel cell elements
- Others had regretted or suggested to contact the above suppliers

Price of fuel cells

Fuel Cell	Price (US$ per kW		
	Present	Forecast	
		Stationary	Transportation
Phosphoric acid (PAFC)	4000-4500	1500	
Polymer electrolyte membrane (PEMFC	3500-15000	700-800	30-50
Molten carbonate (MCFC)	>15000	1500	
Solid Oxide Fuel Cell (SOFC): tubular design with/without micro-tubine	10000-25000	1200 for 1-5MW plants	
Solid Oxide (SOFC): Planar design	>10000	700-1000	

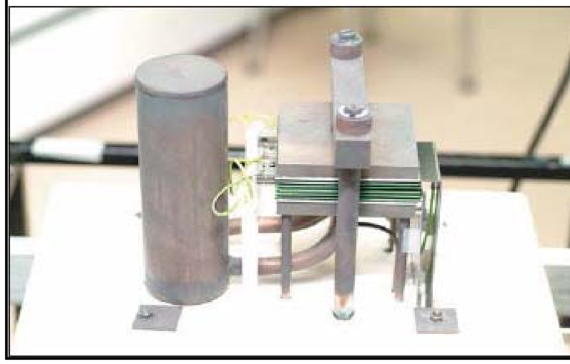
The terms and conditions given by the suppliers of the Solid oxide fuel cell HT ceramix supplier of fuel cell stack.

- **HT Ceramix, Switcher land**
  - **Offer against the purchase enquiry** HT Ceramix 100W five cell stack Total cost - € **24,150 : Rs. 14,24,850 and for 20W** € **20,400, Rs.12,36,000**
- HTc agrees to supply a stack for educational / technical evaluation purpose laboratory/ prototyping conditions.
- HTc grants a free, non-exclusive non-transferable license limited to the sole purpose evaluation HTc' SOFC stack.
- The stack should be tested as per procedure outline by HTc. If HTc products applied failure by the customer to communicator to and consult with HTc on testing and evaluation procedures or any other purpose to which HTc products are applied invalidates all or any warranty, product liability, patent infringement or indemnification, express or implied, for which HTc may be liable world wide.

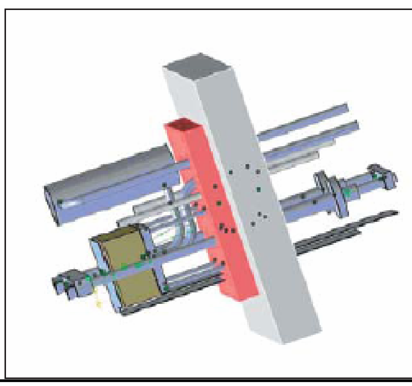
The terms and conditions given by the suppliers of the Solid oxide fuel cell HT ceramix supplier of fuel cell stack. (cont.)

- The customer shall not allow its collaborators or anyone else to reverse engineer or execute analysis of any kind either directly or indirectly on the dimensions, chemical composition, microstructure, surface morphology, method of manufacture or assembly of the cell, as diffusion & distribution layer, current collection layer and the stack itself.
- **The customer, upon the completion of the useful life of the stack, shall return the stack to HTc for appropriate disposal.**
- **The stack initial performance is guaranteed for 24 hours if the HTc startup procedure is followed and the operating condition respected.**
- **The HT ceramix has suggest to buy the test equipments from Advanced Measurements, Canada.**
- These results were obtained under our ideal laboratory conditions. HTceramix offers no guarantee of identical performance under other laboratory conditions.
- This offer is made pursuant to the laws of the Canton de Vaud, Switzerland.

HOT COMPRESSION KIT



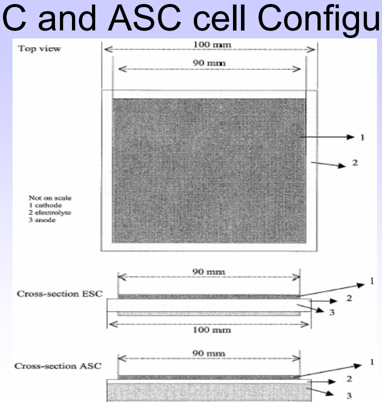
INSULATING PLATE AND A TEST FIXTURE



QUOTATIONS FROM THE SUPPLIERS OF SOFC CELL ELEMENTS

- **InDEC (HC Starck), Netherland**
  - Offers only fuel cell elements (anode, cathode and electrolyte)
  - Do not offer the stack
  - Has suggested to contact stack design engineers for consultancy and bear the consultancy charges.
  - The consultancy charges for advising the stack engineering was indicated as us $ 25,000 however they do not give guarantee.
  - Has suggested to buy the stack test equipment from (ECN)
  - Has given offer for three types of fuel cell elements
    - Anode supported (ASC1, ASC2)
    - Electrode supported cells (ESC2)
    - We have to buy minimum 10 cells

ESC and ASC cell Configuration



Offers from the Fuel Cell Test Equipment

S.No	Company	Quotation amount
1	Advanced measurements	$131,400 Canadian dollar Rs. 60,44,400
2.	ECN, Netherland	€1,28,000 Rs.73,45,011
3.	VB Ceramics, India	Rs. 12 lakhs Negotiated to 8 lakhs.

Quotations from the suppliers of SOFC test rig.

S. No	Company	Quotation amount	Remarks
1	Advanced measurements	$131,400 Canadian dollar	**1. The supply includes** a. Gas flow system with control for both fuel and oxidizer b. Heat exchanger to cool producer gas with air c. Pre heater to heat to 800C d. Furnace – 1000C rating -system e. Data acquisition and control f. Electronic Load g. Piping and tubing **2. They will provided at extra cost the following Regulated supply of clean producer gas** a. Fuel cell manifold b. UPS c. Gas detection (Can be offered at extra cost)

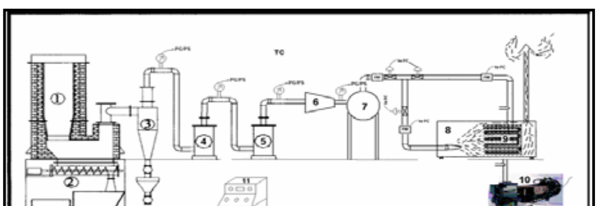
Quotations from the suppliers of SOFC Test rig. (cont.)

2.	ECN, Netherland	€1,28,000	1. Informed over phone, detailed quotation yet to be received 2. ECN will provide support knowledge on assembly, conditioning / startup procedure, operation etc only when decide to purchase the test rig from them. 3. For information on stack design only when consultancy agreement signed and payment is made separately for this knowledge. 4. However ECN does not give guarantee whatsoever on performance, endurance as this technology is still under development.

Quotations from the suppliers of SOFC Test rig. (cont.)

3.	VB Ceramics, India	Rs. 8 lakhs	1.The supply includes a. Producer gas pre treatment plant b. Compressor assembly c. Reservoir tank d. Mass flow controller e. Heat exchanger f. Vacuum furnace g. Pipe lines h. Electronic load i. Control panel j. Data acquisition (controlled from the control panel not from the computer) 2.They will provided at extra cost the following 1. Data acquisition system and control software

The process followed for the purification of producer gas

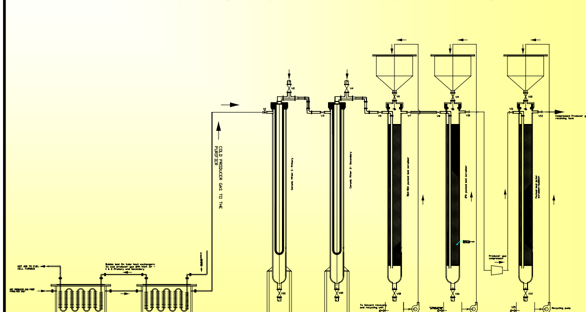


LIST OF PROJECTS AND EQUIPMENTS USING PRODUCER GAS AS FEED STOCK

A. Preparation and refining of producer gas
B. Common Furnace for Heating the working fluid
C. Solid oxide Fuel cell
D. Common Control panel

S.NO		LIST OF EQUIPMENTS	S.NO		LIST OF EQUIPMENTS
01	A	REACTOR	07		HIGH PRESSURE INSULATED RECEIVING
02		SCREW CONVEYOR	08	B	FURNACE CHAMBER WITH BURNER
03		CYCLONE SEPARATOR	09		HEAT TRANSFER TUBES
04		CERAMIC COARSE FILTER			a. TO HEAT THE PRODUCER GAS FROM 400-1000C b. TO HEAT THE HELIUM FROM 30-750C c. TO HEAT THE VEGETABLE OIL FROM 30-350C
05		CERAMIC FINE FILTER	10	C	SOLID OXIDE FUEL CELL
06		COMPRESSOR	11	D	CONTROL PANEL

Producer Gas Purification Unit



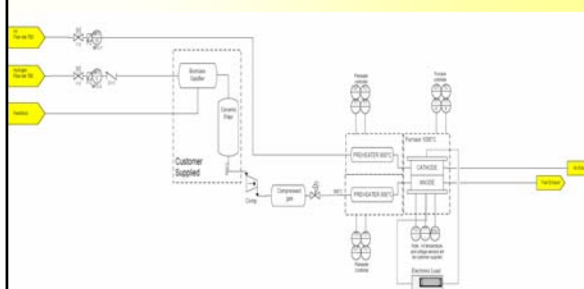
PRODUCER GAS PURIFICATION UNIT

Producer Gas Purification Unit

Ceramic Filter Elements -CALDO Engineering, UK

INSERTION OF CERAMIC FILTER INTO THE FILTER ASSEMBLY

PROCESS FLOW DIAGRAM OF THE TEST RIG FOR SOFC



LIST IMPORTANT EQUIPMENTS, COMPONENTS AND INSTRUMENTS

- Fuel processing
  - Hot producer gas filtration equipment
  - Cooling of producer gas – heat exchanger
  - Producer gas compressor
  - High pressure producer gas receiver
  - Pressure regulator for producer gas
  - Flow measurement and control system for producer gas
  - Heater for the producer gas to heat from room temperature to around 850^{0}C
  - Thermocouples 8 numbers
  - Pressure sensors transducers 4 numbers
  - Temperature indicator cum recorder – I No.

LIST IMPORTANT EQUIPMENTS, COMPONENTS AND INSTRUMENTS

- Oxidizer processing
  - Air compressor
  - Air receiver
  - Air pressure regulator
  - Air flow meter and controller
  - Air heater from room temperature to around 850^{0}C
  - Thermocouples 6 numbers
  - Temperature indicator cum recorder – I no.
  - Pressure sensors – 2 nos.
  - Flow meters with control valve
- Fuel cell assembly
  - Single / multi cell stack – 2 nos.
  - Fuel and oxidiser inlet plumbing lines and nozzles – 1 set
  - Producer gas

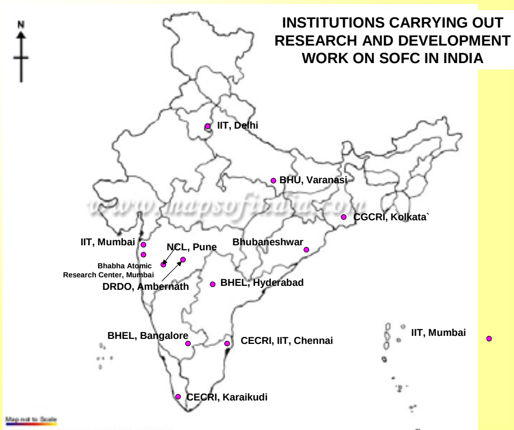
LIST IMPORTANT EQUIPMENTS, COMPONENTS AND INSTRUMENTS

- Fuel cell assembly
  - Single / multi cell stack
  - Fuel and oxidizer inlet plumbing lines and nozzles
  - Product gas piping
  - Thermocouples
  - Fuel cell furnace
  - Fuel cell gaskets
  - High temperature adhesive for fuel cell
- Performance evaluation equipments
  - Voltmeters, ammeter, Energy meter
  - Data acquisition system with monitor and printer
- Fuel cell test equipment
- Tools and fixtures

Summary & Requirement

- Present status of research on SOFC in other laboratories in India
  - The following laboratories have reported that they are carrying out research in fuel cell and also in SOFC.
    - Central Glass and Ceramic Research Institute, Calcutta – CGCRI
    - Central Electrochemical Research Institute, (CECRI), Karaikudi &Chennai

INSTITUTIONS CARRYING OUT RESEARCH AND DEVELOPMENT WORK ON SOFC IN INDIA



Details from CGCRI, Kolkata on SOFC

- CGCRI scientist working on the SOFC has informed that development of kW level SOFC is one of the current multi crore CSIR –NMITLI project
  - He was called back from abroad specifically to establish this laboratory
  - He has worked in USA, Germany, Canada and Japan for 8 years directly on SOFC with Siemens-Westinghouse/Penn state, Forschugszentrum Juelich and McMaster university and Ishihara's group.
  - 20 scientist including 5 JRFs are working on SOFC project in CGCRI
  - Have imported test rig to evaluate the performance
  - They are carrying out the research with commercially available pure hydrogen.
  - SOFC design is extremely complicated compared to PEM and PAFC stacks. In his opinion there is nobody working on SOFC with producer gas as feed stock.
  - **Information from CECRI, Karaikudi is yet to be received**
  - **Fuel cell Research centre at Chennai has separate laboratory space with 7 scientist and supporting staff. CSIR has spent considerable amount in establishing facilities.**

Control Panel for the fuel cell

Research and Development Challenges for SOFC

SOFC Tubular design	• High cell and stack fabrication cost • Long start-up/shut-down times (upto several hours). • Significant thermal shielding required to avoid heat losses • Difficulties in the management of electrical and thermal load demands, as well as in temperature maintenance.
SOFC Planar Design	• Selection and poor life – time of interconnect and sealing materials • Lower operating temperature so that cheap metallic interconnect materials can be used with minimal cell degradation. • Poor thermal cycling capability • Sealing and thermal compatibility issues. • High rates of cell degradation during operation • Long start-up/ shut –down times (up to several hours). • Significant thermal shielding required to avoid heat losses. • Difficulties in electrical and thermal load demand, as well as in temperature maintenance.

PROBLEMS FOR NEW DEVELOPERS (IMPEDIMENTS)

- It is too expensive for any new laboratory to attempt to develop different elements required for manufacturing Solid Oxide Fuel Cell.
- Laboratories around the world are reluctant to share their knowledge on practical aspects of solid oxide fuel cell.
- The fund made available from the funding agency in India is too meager to attempt any reasonable research and development on Solid Oxide Fuel Cell.
- Even the limited number of personals working on SOFC development are not having specific goal to commercialize the technology.

PROBLEMS FOR NEW DEVELOPERS (IMPEDIMENTS) – cont.

- Every scientist will be happy to see the outcome of his research is put into use for wider social cause. It is possible only when commercial scale production units are installed. The execution of any project calls for the contribution of different developing agencies with a team to co-ordinate and a lead person. It is time for India to plan creation of an organization exclusively for fuel cells research, development and manufacture.
- In the absence of a Central agency to integrate the research efforts of different laboratories, academic institutions in fuel cell research may go waste or under utilized as though there is no commitment in the country to commercialize Solid Oxide Fuel Cell based power plants.

CONCLUSION AND SUGGESTIONS

- Government of India should form a separate organization similar to ISRO to consolidate the research and development activities progressing in different laboratories and academic institution in the country and realize commercial scale plants in project mode.
  - The present laboratories working on different element can also continue to do their research getting the fund through the centralized organization.
  - The new organization should be given clear mandate for developing solid oxide fuel cell power plants integrated with co generation units
  - In absence of creation of an exclusive organization, India will have only pockets of researchers carrying out research without any definite aim and purpose.

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