

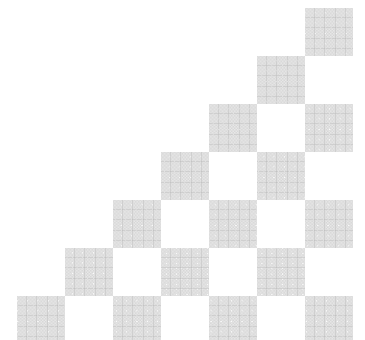


Specialty Vehicles and Material Handling Equipment

Matching Federal Government Energy Needs with Energy Efficient Fuel Cells

U.S. DOE and USFCC Fuel Cells Meeting
April 26, 2007

William L. Mitchell, Vice President
Nuvera Fuel Cells
(617) 245-7623 ♦ mitchell.w@nuvera.com





U.S. Fuel Cell Council

Micro & Man-Portable

- Less Than 100 Watts
- Consumer electronics, defense (solder power), speciality applications

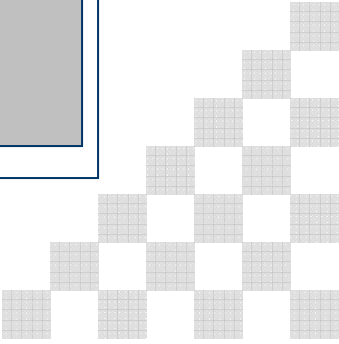
Portable, Backup, APU

- 100 Watts to 10 Kilowatts
- Battery replacement or charging, defense (platoon power), telecom backup, remote, auxiliary power

Buildings & Facilities

- 100 Kilowatts to Megawatts
- Consumer electronics, defense (solder power), speciality applications

Speciality vehicles & Material handling

- 1 to 50 Kilowatts
 - Forklifts, airport tugs
- 

Transition Applications and Markets – Specialty Vehicles

Specialty Vehicles

- Lift Trucks/Forklifts
- Automated Guide Vehicles
- Mining Vehicles
- Personnel Carriers
- Burden Carriers
- Industrial Utility Vehicles
- Golf Carts
- Turf Maintenance Vehicles
- Commercial Sweepers
- Ice Resurfacers
- Wheelchairs
- Lawn Mowers
- Unmanned Undersea Vehicles
- Unmanned Aerial Vehicles
- Motorized Bicycles/Scooters



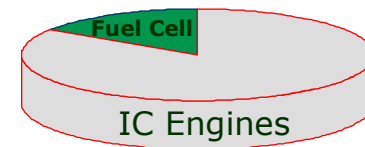
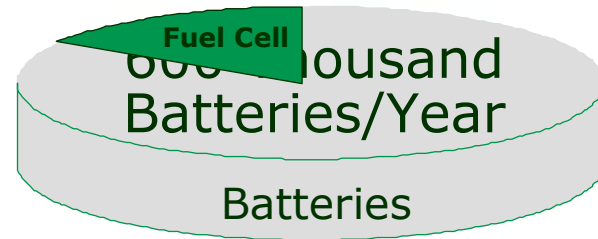
Material Handling Market Size

4.5 Million
Existing Forklift
Truck Fleet

560 Thousand
New Trucks Sold
in 2005

235 K
Electric

325 K
IC Engine



Goals

- 1) Capture High Productivity Users' Business
- 2) Accelerate Internal Combustion to Electric Conversion

WHY FUEL CELLS?

COMPARISON OF TWO APPROACHES

BATTERY ONLY



ANNUAL OPERATING COSTS PER TRUCK
(\$ THOUSANDS)

ANNUAL PRODUCTIVITY GAIN PER TRUCK
(100's OF HOURS)

TIME TO SWAP BATTERIES VS. REFUELING
(MINUTES)

NUMBER OF BATTERY TRAYS

BATTERY ROOM TECHNICIANS

SAFETY

POWER AVAILABILITY
(PER SHIFT)

HYBRID BATTERY / FUEL CELL



Key Parameters and Results

Inputs

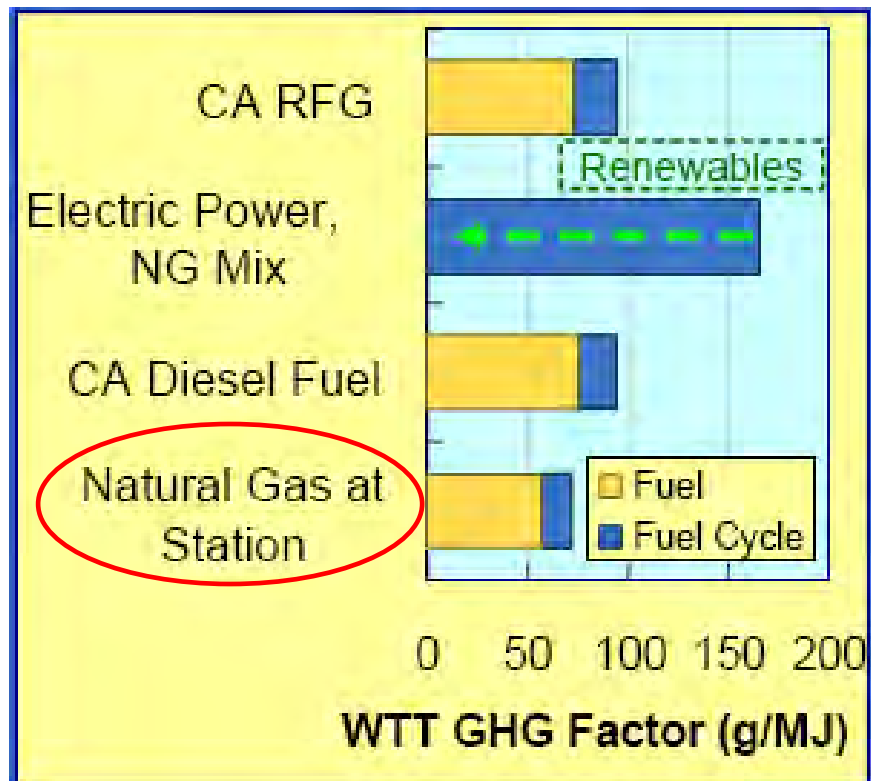
Types of Trucks	Class 1, 2, and 3	No. of Trucks	100
Hours/shift	4.0	Shifts/day	3
Days/year	250	Pick cycles/hr	30 - 90
Operator salary	\$20	H2 tank size	1.5 – 3.0 kg
Hydrogen Price	\$5.00/kg	Electricity price	\$0.09/kWh
Fuel Cell Price	\$3,500/kW	Battery change time	25 min incl. travel time

Outputs

Operating Hrs	3,000 HD/year	Hours Saved	21,200 hrs/yr
NPV	>0	IRR	>35%

Environmental Benefits

“Well-to-Tank” Greenhouse Gas Factors



Source: Societal Benefits Analysis, South Coast Air Quality Management District, Hydrogen Highway Network, 13 August 2004

- ❖ Hydrogen fuel cell vehicles have no GHG emissions
- ❖ GHG emissions are produced upstream as a result of hydrogen fuel production
- ❖ Other than electrolysis from renewable sources (wind, solar), producing hydrogen from natural gas at the station has the lowest carbon footprint
- ❖ GHG from Fuel Cell MHE Equipment are about half that associated with charging battery-powered forklifts

Materials Handling: Market Overview



Market opportunity: replace lead acid batteries in electric industrial vehicles

- forklift battery market: \$1B+ in annual global sales
- target customers: multi-shift, electric forklift and industrial vehicle fleet operators



Market drivers: improves end-user bottom line

- triples run time: eliminates need to replace/recharge batteries
- increased productivity: no loss of power over work shift
- revenue generating: frees up warehouse and factory capacity

Market strategy: demonstrate benefits in end-user customer trials

- Cellex Power and General Hydrogen manufacture, market and sell fuel-cell powered battery replacement packs
- Ballard working to reduce fuel cell cost and increase reliability and durability

Ballard's Go-to-Market Strategy in Materials Handling

1

BALLARD®

Lead Customers

End Users

(select examples)



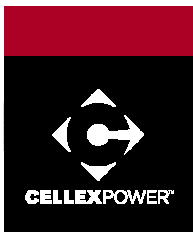
fuel cell design,
development and
manufacturing



systems integration,
fueling and sales to
end customer








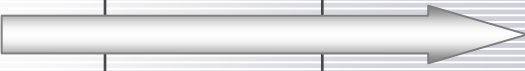
Bridgestone

Wal-Mart

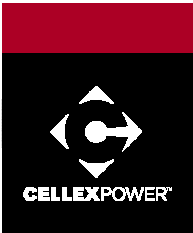


Commercialization Plan for High Throughput Distribution Market



	platform	2006	2007	2008	2009	2010
Pallet Trucks (Class 3) 	3 kW	Beta Units	Early Commercial Units	Commercial Quantities		
Stock Pickers (Class 2) 	3 kW		Beta Units	Commercial Quantities		
Reach & Stand Up CB (Class 2 & 1) 	10 kW			Beta Units	Commercial Quantities	
Sit down CB (Class 1) 	3 kW		Range Extender			
	10 kW				Beta Units	Commercial Quantities





Other Market Opportunities

- Internal Combustion Engine Lift Trucks

- Cellex solution is a zero emission alternative
- Similar power requirements to electric in most segments
- Similar market size to electric lift trucks (~2.7m installed)



- Other Industrial Vehicles

- Airport ground support equipment, mining vehicles, personnel carriers, etc.
- Market size ~0.6m installed





Hydrogenics HyPX[®] Fuel Cell Power Pack



Fully Integrated Solutions Fits Existing Battery Compartment



HyPM Power Module



Electrical & H₂ Storage



Thermal Management



Power Conditioning

- Hybrid system
- Fuel efficient
- Regen capable
- Quiet
- Durable
- Reliable



Hydrogenics HyPX Products For Materials Handling



Products for Class 1 lift trucks and Class 2 reach trucks

Delivering the HyPX™ Product		HyPX™-1-27	HyPX™-1-33	HyPX™-2-21
Nominal Voltage	V	36/48	36/48	36
Size (LxWxH)	mm	975 x 683 x 575	975 x 830 x 575	972 x 514 x 775
	in	38.5 x 26.9 x 22.3	38.5 x 32.8 x 22.3	38.25 x 20.25 x 30.5
Net Power - Peak for 20s	kW	21	21	16
Available Electrical Energy	kWh	21	21	21
Electrical Connection		Anderson SB-350	Anderson SB-350	Anderson SB-350
H2 Fuel Storage Capacity	kg	1.6	1.6	1.6
	lb	3.5	3.5	3.5
H2 Fuel Storage Pressure	bar	350	350	350
	psi	5000	5000	5000
H2 Fuel Fill Port		SAE J2600	SAE J2600	SAE J2600
Ambient Operating Temperature	°C	> 5 to 35	> 5 to 35	> 5 to 35
	°F	> 41 to 95	> 41 to 95	> 41 to 95

Additional specifications available on request. Please contact us for information on the latest HyPX product releases.

Products Ready for Pilot Deployments

Additional Products Under Development

Deka-Nuvera *Total Power Solution (TPS)*



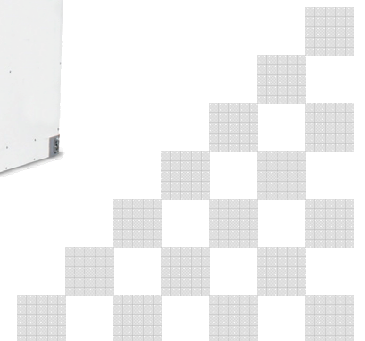
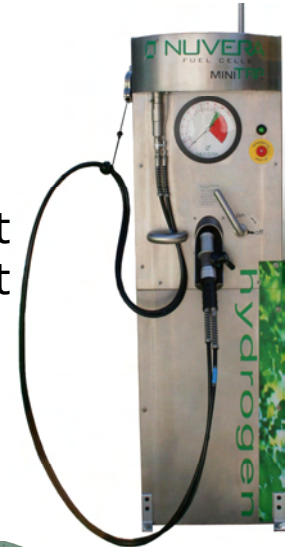
Hybrid fuel
cell power
pack for
forklift trucks



- ❖ East Penn is a leader in motive power solutions—maker of Deka batteries
- ❖ Local service and support



On-site hydrogen
production and fast
refueling for forklift
trucks



Deka-Nuvera *Total Power Solution (TPS)*

- ❖ ReadyPower™ Hybrid Fuel Cell Power Packs can power new trucks - or **re-power older trucks already in service, for superior performance** throughout the shift.
- ❖ TPS provides **on-site generation and storage of hydrogen** from natural gas, for **the lowest cost of hydrogen possible**.
- ❖ **Dispensing equipment located at convenient points** distributed throughout the facility, for **ultra-fast refueling**.
- ❖ A **warranty and service package** that matches the customer's expectations for reliability and quality.
- ❖ **Training** to safely and effectively use the new equipment.



Deka-Nuvera
ReadyPower™
Hybrid Fuel Cell
Power Pack



New OR Existing
Fork Lift Trucks



PowerTap™
Hydrogen Generation
With Indoor Dispensing

**Cost of ownership benefit is payback in 2-3 years
— and even lower for select applications.**

Development Program – Large Scale Electrolysis

- **Stepwise Approach to 100 kg/day then to 500 kg/day**
- **Must be durable, reliable, and more efficient**
- **Significant development already underway for 100 kg/day unit, more needed for 500 kg/day unit**
- **Leverage PEM Fuel Cell Industry Development**

Factory Packaged Hydrogen Stations and Dispensers



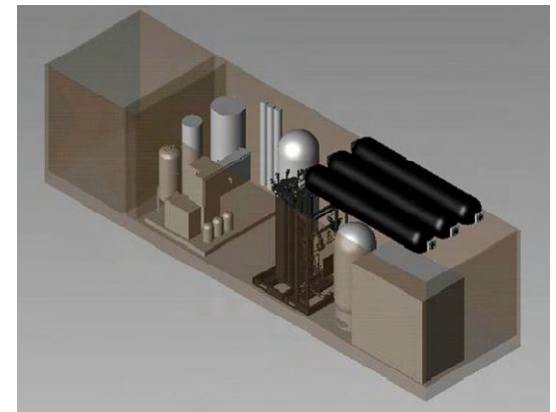
**Factory tested & shipped to site
for easy installation.**

**Includes fuel processor or
electrolyzer for onsite
production.**



GreenField

gti



Developed with support from USDOE

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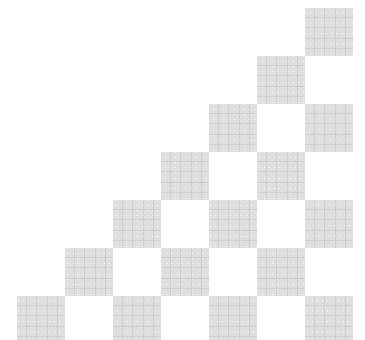


Addendum - Sub Component Supplier Information

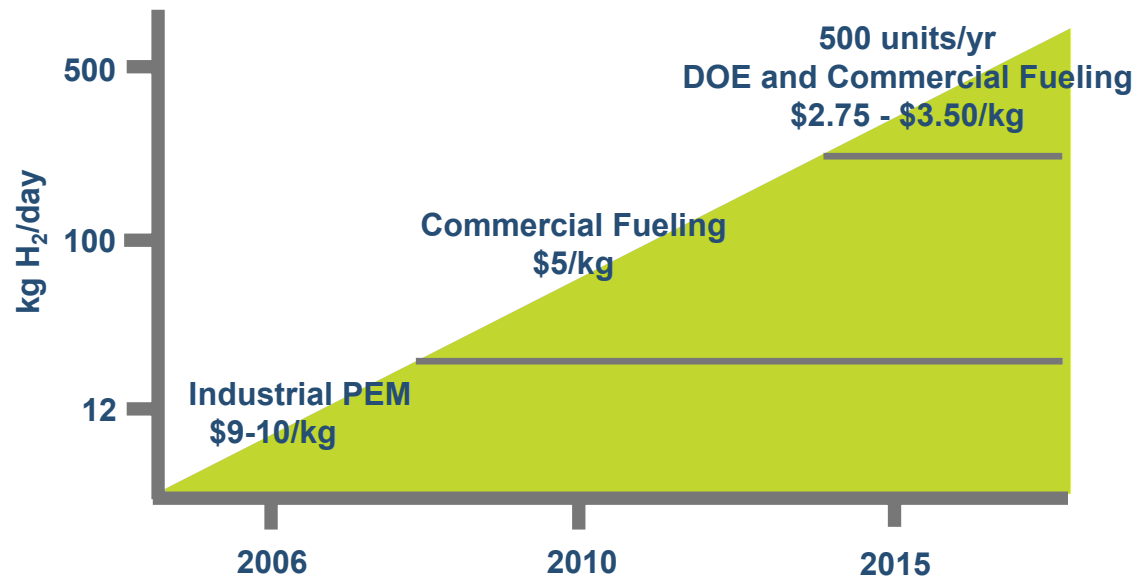
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Pathway to Large PEM Electrolysis



\$/kg H₂ Fuel Cost is Derived from H2A Model

20 year life, \$.04/kwh power, 90% capacity factor

Development Pathway

Cost, Durability, Reliability, Efficiency are Keys

- Design - Product Architecture
- Component R&D
- Subsystem Development
 - Power Supply
 - Cell Stack
 - Balance of Plant
- Prototype Build/Field Tests

H2A Analyses Guide the Cost and Performance Targets for the Major Subsystems

Pathway to 500 kg/day - Power Conversion Goals

- Be Cost and Energy Efficient
 - Increase the percent energy conversion AC in / DC out
 - Decrease \$/watt
- Be Available
 - Manufacture with conventional techniques
 - High reliability, low MTBF – affirm through design, analysis and test
- Be World Compliant
 - 380VAC 50hz 3 phase and 480VAC 60hz 3 phase with transformers
- Compliment Cell Stack Architectures
 - Employ modular architectures for 100, 250, 500 kg/day that match cell stack
 - Meet safety, immunity, emissions standards and directives

Gas Diffusion Layers for PEMFC and DMFC



Freudenberg FCCT develops high quality gas diffusion layers (GDL) that are based on a proprietary non-woven technology. These three dimensional GDL exhibit excellent performance under a wide range of operating conditions and due to their unique matrix construction provide superior processing and handling characteristics.

Our H2315 series is our latest generation of GDL that we offer in untreated and hydrophobic treated versions. In addition, we provide all our styles with or without micro porous layers (MPL).

As a customer focused company, we invite you to explore with us to select the best combination of GDL for your specific application and we can further assist you to solve any sealing problems you may have by integrating seals on our GDL that will conform to your cell design.

H2315 (untreated)

The untreated GDL is offered to customers who prefer to carry out their own finishing step.

H2315 T10A

This basic hydrophobic treated GDL without an MPL is recommended for "wet" PEMFC conditions and DMFC applications (emphasis on cathode side).

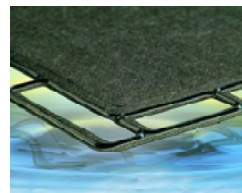
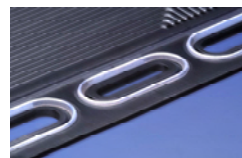
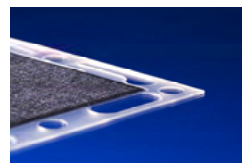
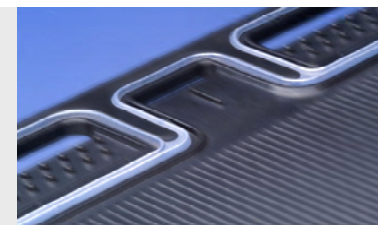
H2315 I6

Our hydrophobic style H2315 I6 is recommended for a wide range of operating conditions in stationary and portable applications where no MPL is required. In addition, it exhibits excellent performance in DMFC applications (emphasis on cathode side).

H2315 I3 C1 / H2315 T10AC1

This improved hydrophobic treated GDL with MPL is suggested for typical operation conditions and found in automotive, stationary and portable applications. It is also recommended for DMFC applications (emphasis on anode side).

Fuel Cell Seals



Fuel Cell Stack Sealing is Critical to Optimum Performance:

- □ durable leak free solutions
- □ accommodate and balance tolerances
- □ control of stack performance
- □ ease of assembly with safe component positioning and fixation

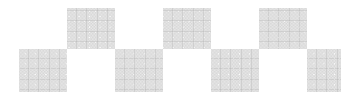
Freudenberg & NOK companies are leading worldwide sealing suppliers. We leverage our know-how in design, materials and processes to produce customized Fuel Cell stack sealing solutions

integrated seal on

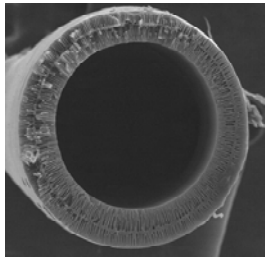
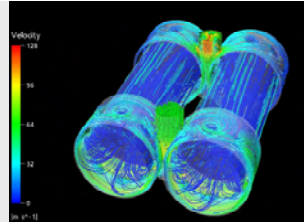
- □ Bipolar plates
- □ Gas Diffusion Layers
- □ MEA
- □ with flexible circuits

loose gaskets

- □ flat or profiled
- □ reinforced



Fuel Cell Humidifier



Hollow fibre

A perfectly matched design of humidifier and stack is important for ensuring optimal fuel cell performance and durability.

Our innovative Humidifier are designed to meet the needs of our customers:

- High water transfer efficiency
- Low pressure drop
- Customized packaging and design
- Freezing resistance and mechanical strength
- Economical manufacturing processes
- Applicable for automotive, stationary and portable PEM Fuel Cell systems



Humidifier for low pressure applications

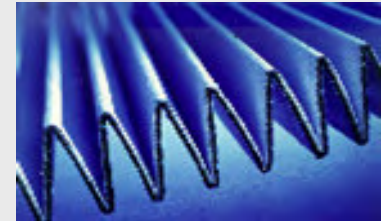


Humidifier for pressurized applications

NOK and Freudenberg offer

- High experiences in fuel cell humidification
- Customized solutions
- Standardized concepts

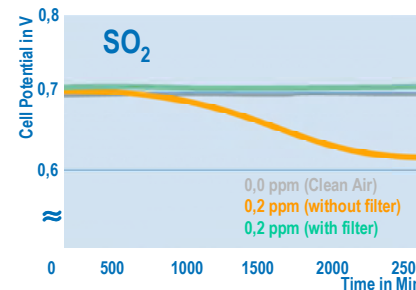
Fuel Cell Filters



Particle & Chemical Filter

Filtration is essential for high durability and better performance. Fuel Cells must be protected from environmental hazards, including:

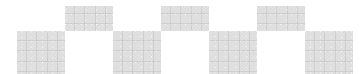
- Harmful gases
- Dust particles
- Soot particles
- Salt aerosols



Effects of SO₂ on cell performance with and without filter

Our fuel cell particle & adsorption filters are specifically engineered to protect against particulate and gaseous hazardous substances. They offer:

- Long life
- Low pressure drop
- High efficiency



GrafTech Bipolar Plate Activity in Specialty Vehicle/MHE

- GrafTech provides GRAFCCELL® bipolar plate materials for Ballard Power Systems Inc. Mark 9 SSL™ fuel cells
- Ballard announced in October 2006 that it will provide 2,900 Mark 9 fuel cells, in the power range of 4-20kW, for General Hydrogen Corporation that they will integrate into products being sold to customers for their materials handling fleets. Shipments will take place in 2007/2008. In January '07 Cellex Power Products announced they completed successful fuel-cell pallet-truck trials at two Walmart distribution centers in Ohio using Ballard Mark 9 SSL™ stacks



Ballard Mark 9 SSL™ Fuel Cell Stack



GRAFCCELL® Bipolar Plate



Cellex Class 3 Pallet Truck

» SSL™ is a trademark of Ballard Power Systems. GRAFCCELL® is a trademark of GrafTech International Ltd. Fuel cell stack picture obtained from Ballard web site. Cellex pallet truck picture obtained from Cellex web site.

GrafTech Bipolar Plate Activity in Specialty Vehicle/MHE

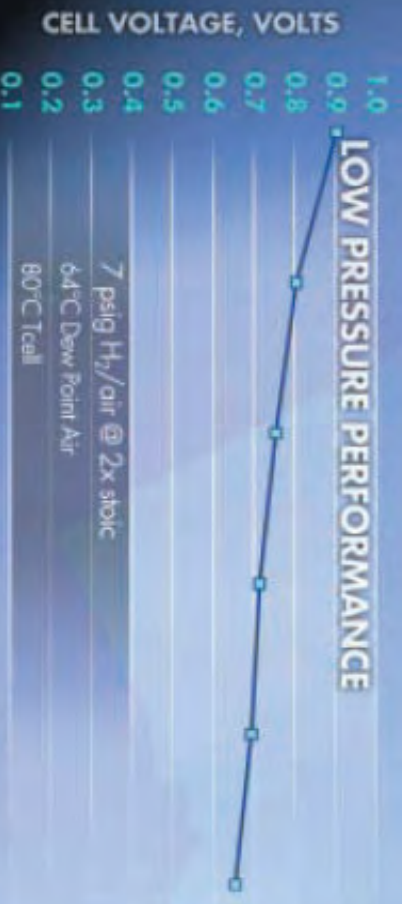
- Industry needs :
 - Current bipolar plate manufacturing technologies are sufficient for 100,000's of plates/year
 - By next decade will need capabilities for 10,000,000's of plates/year – not cost optimized with current manufacturing technologies
 - Workshop on “Manufacturing R&D for the Hydrogen Economy”, July 2005 highlights “high priority” need for high speed forming and joining processes for bi-polar plates.
 - GrafTech and it's partners will submit a proposal to develop high speed forming/joining capabilities for GRAFCELL® bipolar plates that meets DOE Targets

Ion Power has developed a unique design and manufacturing process for polymer electrolyte membrane electrode assemblies (MEAs) used in hydrogen fuel cell applications. Utilizing over 40 years of experience in working with DuPont's Nafion® membrane, our process delivers low resistance, durable and consistently high performing MEAs for PEM fuel cell applications.

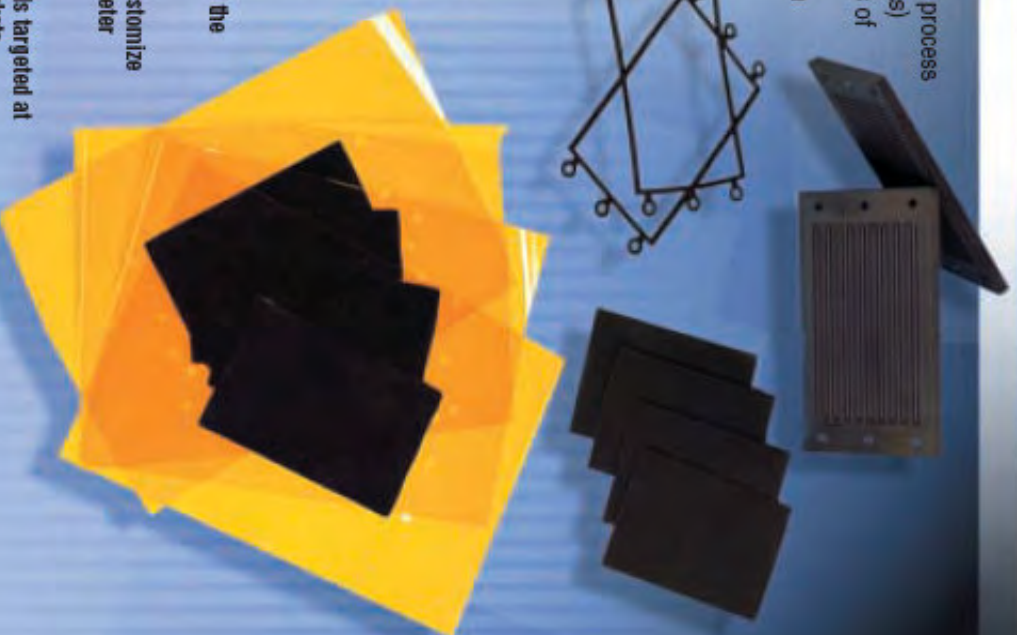
Ion Power's line of membrane electrode assemblies offers the following advantages:

- Ultra-thin (<30 micron) unreinforced Nafion® membranes result in high power density, low resistance structures
- The stable Nafion® ionomer used as the membrane component insures long component life tolerating repeated swell and dehydration cycles
- Unique fabrication process replaces the membrane component in the non-active region with a less expensive high strength material thus lowering system costs and eliminating stress failures typically found along the active area edge
- Ease of recycling of the ionomer and platinum component of the catalyst coated membranes
- Flexibility of design options gives Ion Power the ability to customize MEA catalyst loading, membrane thickness, size, and perimeter configurations
- A diverse product line, providing MEAs designed for fuel cells targeted at stationary power, portable power, and the transportation markets

In operation for over three years, Ion Power's MEA manufacturing pilot line is set up to handle the prototype and production requirements of today's growing PEM fuel cell industry. So whether you need one or thousands of catalyst coated membranes for hydrogen fuel cells, DMFC, or water electrolyzers, contact Ion Power to discover how your application can "Turn On With Ion Power Catalyzed Membranes."

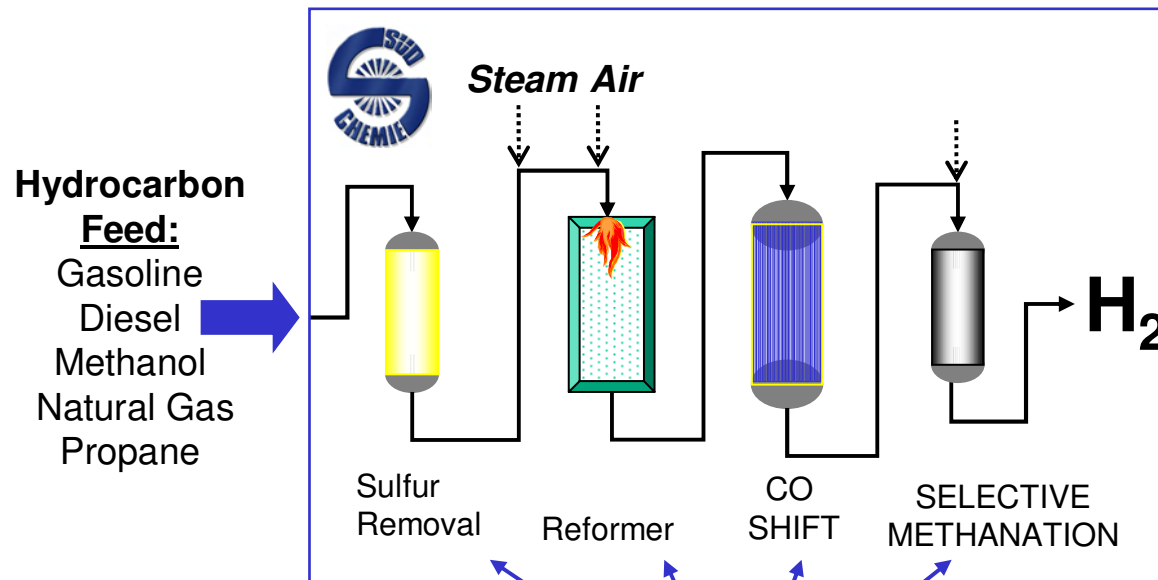


Ion Power's catalyst coated membranes with 25 micron membrane thickness offer high power density under low pressure humidified air conditions. Test conditions: 7 PSIG humidified air (dew point 64°C) at 2x stoichiometry, cell operating temperature 80°C, test point duration time of 7 hours.

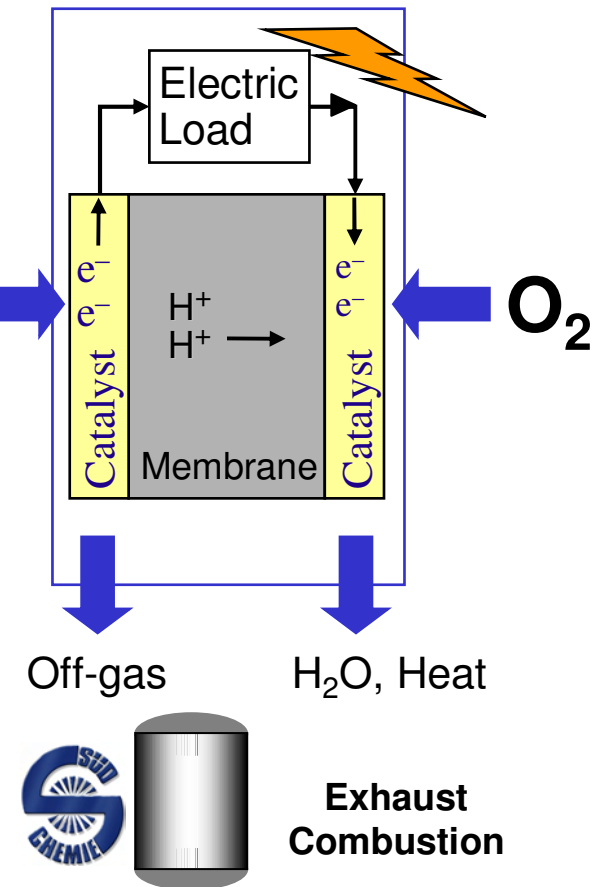


Süd-Chemie Fuel Processing for Fuel Cells

Fuel Processor

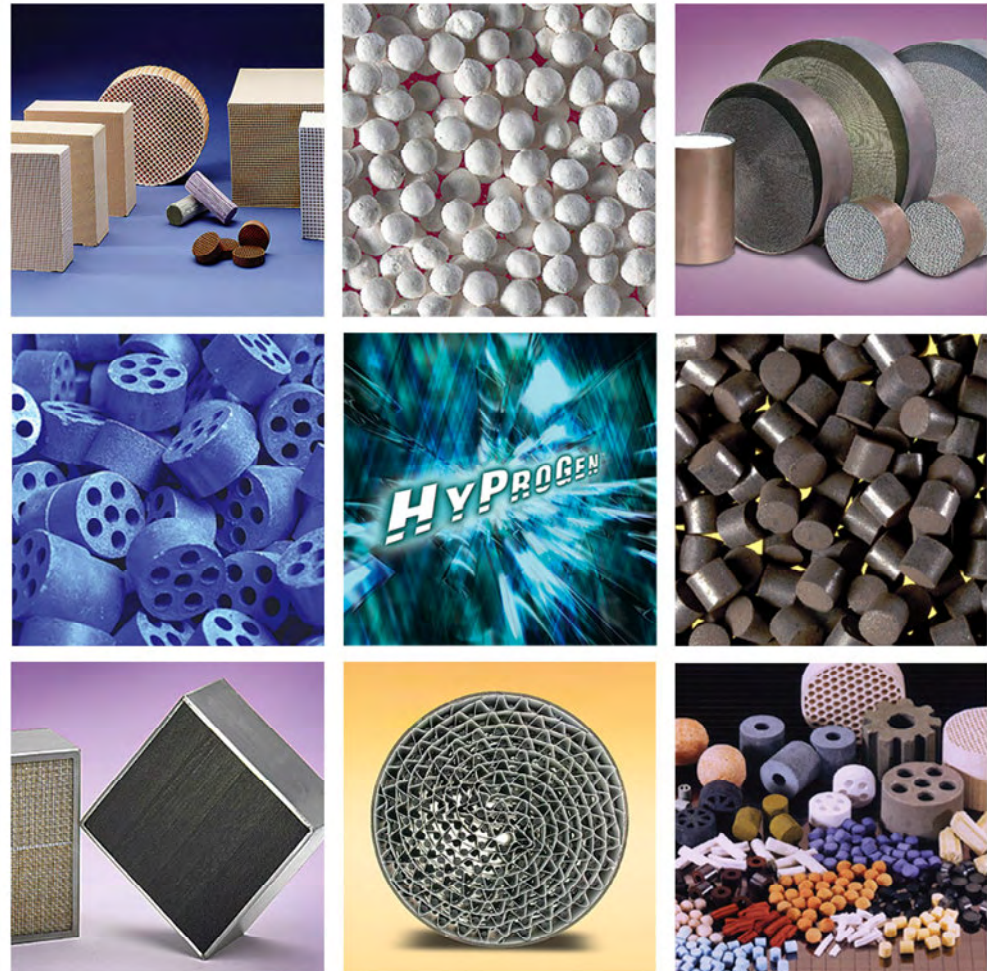


Fuel Cell Stack



Hydrogen Catalysts of every type, shape and formulation

- Precious and base metal
- Washcoated on metal, ceramic or foam monoliths
- Extruded
- Pelletized
- Granulated
- Custom shapes to optimize your designs



- **Commercial Hydrogen Production Catalysts**

- Feed Purification

- Co/Mo, Ni/Mo Hydro-Desulfurization catalysts: HDMAX product line
- High capacity ZnO H₂S traps: ActiSorb product line

- Hydrocarbon Reforming

- Carbon Tolerant, nickel based steam primary and pre-reforming catalysts: ReforMax product line

- Water-Gas Shift

- Fe/Cr/Cu and Cu/Zn/Al high and low temperature shift catalysts: ShiftMax product line

- ***HYPROGEN*[™] Product Line for Distributed Hydrogen Production**

- Feed Purification

- High capacity, ambient temperature desulfurization sorbents
- Non-hazardous Hydro-Desulfurization catalysts

- Hydrocarbon Reforming

- Base and precious metal steam, auto-thermal and partial oxidation catalysts for compact reformers

- Water-Gas Shift

- Robust precious metal catalysts
- Non-pyrophoric, self-activating base metal catalysts

