Specialty Vehicles and Material Handling Equipment

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

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Nuvera Fuel Cells
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<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Micro &amp; Man-Portable</strong></td>
<td>• Less Than 100 Watts&lt;br&gt;• Consumer electronics, defense (solder power), speciality applications</td>
</tr>
<tr>
<td><strong>Portable, Backup, APU</strong></td>
<td>• 100 Watts to 10 Kilowatts&lt;br&gt;• Battery replacement or charging, defense (platoon power), telecom backup, remote, auxiliary power</td>
</tr>
<tr>
<td><strong>Buildings &amp; Facilities</strong></td>
<td>• 100 Kilowatts to Megawatts&lt;br&gt;• Consumer electronics, defense (solder power), speciality applications</td>
</tr>
<tr>
<td><strong>Speciality vehicles &amp; Material handling</strong></td>
<td>• 1 to 50 Kilowatts&lt;br&gt;• Forklifts, airport tugs</td>
</tr>
</tbody>
</table>
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 Resurfacters
- 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
- 600 Thousand Batteries/Year
- 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

<table>
<thead>
<tr>
<th>Battery Only</th>
<th>Hybrid Battery / Fuel Cell</th>
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<tr>
<td>Annual Operating Costs Per Truck ($ Thousands)</td>
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<td>Annual Productivity Gain Per Truck (100's of Hours)</td>
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<td>Time to Swap Batteries vs. Refueling (Minutes)</td>
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<tr>
<td>Number of Battery Trays</td>
<td></td>
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<td>Battery Room Technicians</td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td></td>
</tr>
<tr>
<td>Power Availability (per shift)</td>
<td></td>
</tr>
</tbody>
</table>
### Key Parameters and Results

#### Inputs

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

#### Outputs

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Hrs</td>
<td>3,000 HD/year</td>
</tr>
<tr>
<td>Hours Saved</td>
<td>21,200 hrs/yr</td>
</tr>
<tr>
<td>NPV</td>
<td>&gt;0</td>
</tr>
<tr>
<td>IRR</td>
<td>&gt;35%</td>
</tr>
</tbody>
</table>
Environmental Benefits

“Well-to-Tank” Greenhouse Gas Factors

- 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

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

making fuel cells a commercial reality
Ballard’s Go-to-Market Strategy in Materials Handling

**Lead Customers**
- Ballard
- General Hydrogen
- CELLEXPOWER

**End Users**
- Bridgestone
- Wal-Mart

fuel cell design, development and manufacturing

systems integration, fueling and sales to end customer

making fuel cells a commercial reality
<table>
<thead>
<tr>
<th></th>
<th>platform</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pallet Trucks (Class 3)</td>
<td>3 kW</td>
<td>Beta Units</td>
<td>Early Commercial Units</td>
<td>Commercial Quantities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stock Pickers (Class 2)</td>
<td>3 kW</td>
<td>Beta Units</td>
<td></td>
<td>Commercial Quantities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reach &amp; Stand Up CB (Class 2 &amp; 1)</td>
<td>10 kW</td>
<td></td>
<td>Beta Units</td>
<td></td>
<td>Commercial Quantities</td>
<td></td>
</tr>
<tr>
<td>Sit down CB (Class 1)</td>
<td>3 kW</td>
<td></td>
<td>Range Extender</td>
<td></td>
<td>Beta Units</td>
<td>Commercial Quantities</td>
</tr>
</tbody>
</table>
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

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

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.

Developed with support from USDOE
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Addendum - Sub Component Supplier Information

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Pathway to Large PEM Electrolysis

$/kg H_2 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
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).

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Gas Diffusion Layers for PEMFC and DMFC

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Fuel Cell Seals

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**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
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

NOK and Freudenberg offer
- High experiences in fuel cell humidification
- Customized solutions
- Standardized concepts

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

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 GRAFCELL® 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.
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
  – GrafTech and it’s partners will submit a proposal to develop high speed forming/joining capabilities for GRAFCELL® bipolar plates that meets DOE Targets
A reverse product that provides MEA designed for fuel cells targeted at stationary power, portable power, and the transportation markets.

- Quick turnaround times
- A wide array of loadings, membranes, thicknesses, sizes, and formats
- Cost-effective and membrane can be tailored for film, PSA, or powder

For polymer electrolyte membrane electrode assemblies (PEM) fuel cell application, the following advantages:

1. Wide range of manufacturing experience and PEM cell development, including process development for PEM fuel cell technologies, and consistent high performance of membrane electrodes and associated fuel cell components.
2. Leading edge in research and development, with more than 40 years of experience in fuel cells.
3. Ion Power has developed a unique design and manufacturing process for PEM fuel cells.
Hydrocarbon Feed:
- Gasoline
- Diesel
- Methanol
- Natural gas
- Propane

Fuel Processor:
- Sulfur Removal
- Reformer
- CO SHIFT
- SELECTIVE METHANATION

Fuel Cell Stack:
- Electric Load
- Catalyst
- H₂
- O₂
- Off-gas
- H₂O, Heat
- Exhaust Combustion

The World’s Most Advanced Hydrogen Catalysts—Empowering the Global Fuel Cell Industry
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
**Süd-Chemie Products**

- **Commercial Hydrogen Production Catalysts**
  - Feed Purification
    - Co/Mo, Ni/Mo Hydro-Desulfurization catalysts: HDMAX product line
    - High capacity ZnO H\(_2\)S 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