FORZA™ Rail Power Module

2nd INTERNATIONAL HYDROGEN TRAIN AND HYDRAIL CONFERENCE

Herning, Denmark - June 7th 2006
Nuvera Company Overview

Nuvera is focused on the commercialization of hydrogen-based energy systems containing advanced fuel processors and/or PEM fuel cells.

- Diverse set of shareholders
- Product development focus
- Company differentiators:
  - Metallic stack architecture
  - Design for industrial applications
Product Development Portfolio

- **PowerFlow™** (5 kWe H2PMs for industrial trucks)
- **PowerTap™** (NG-based H2 generator: 50 kg/day)
- **Forza™** (120 kWe H2PMs for Chloralkali plants)
- **Avanti™** (NG, 4.6 kWe, $\eta > 30\%$ net HHV, CHP plant)
- **STAR™** (on-board gasoline FP subsystem)
- **Andromeda™** (automotive FC stack ass’y)
Metallic hardware

**Standard approach**
- Graphite material based \((10-30 \text{ $/kg})\)
- Flow fields curved on the plate

**Nuvera approach**
- Flat SS plate \((5.5 \text{ $/kg})\)
- SS porous structure

**OEM (GM, Honda, Toyota, DC)** are studying ways to operate the transition to metal plates for achieve DOE targets.
Cathode Water Injection

Fuel cell temperature can be managed using sensible or latent heat.

CWI Technology
- Stack size reduction
- Reduced BOP
- Reduced air blower & HX fan parasitics
- Flowfield enhancement
- Patented technology

CWI is used exclusively for thermal regulation of the XDS-900 stack.
FCS in several vehicle architectures

Year 2000

APU-Range Extender

FIAT SEICENTO HYDROGEN

Panda HYDROGEN

Two other fuel cell vehicles are also presented: a FIAT SEICENTO HYDROGEN and a Panda HYDROGEN.

Year 2004

Efficiency improvement evolution

The image demonstrates the evolution of efficiency improvements in fuel cell vehicles from the Year 2000 to the Year 2004.
Andromeda II stack performance

- Current Density (A/cm²)
- Average cell voltage (V)

Andromeda II specs. sheet

- 78 liters volume
- Max height = 210mm
- 140kg weight
- Voltage range = 230-384V
- Operating Power < 80 kW
- Two connections per fluid
- BOB integrated
- T range = 40-72°C (dry) 40-80°C (humid)
- T storage = -20°C
- T start up > -20°C
FORZA™ - Initial target are electrochemical plants

UP TO 20% OF ENERGY SAVINGS – 100% POLLUTION FREE

NaCl Water Electricity
IN

Heat + Water + DC Current

FORZA Modular Systems

NaOH Cl2
OUT

Heat + Water + DC Current

BY PRODUCT Hydrogen

Installation on C/A plants is covered by a Nuvera patent: “Method for the integration of fuel cells into electrochemical plants”, Pat.No 6,423,203 B1 Dated Jul 23,2002
System testing (Nuvera - UHDE-NORA)

FORZA Core Module + BOP
8 x 116 cell stacks (>650 V)
Net power ~120 kWe

Fuel Cell Qualification Lab
Osio, ITALY
Single cell (full active area) durability

Nuvera Fuel Cells Durability Testing on PRIMEA 5621 MEA

(H₂-N₂ fuel mix, low pressure, direct cathode water injection)

A single cell test on full active area (500 cm²) MEA and all other full scale stack materials and design considerations (metallic components, flowfield design, reactant feeds, etc.)

8% decay
(-6 µV/hr)
Results: 100 MWh Milestone

The FORZA Core Module passed its first major operational milestone: production of 100 MWh of electric power with > 90% Availability.
System testing in a chlorate plant

Chlorate cell room (Italy)

Skid installation (120 kW)

Power electronics

Control Box
An Evolution from...
...To The Ultimate in Clean Transport
Fuel Cell Advantages for Locomotives

- Over Diesel Engine
  - Torque
  - Efficiency
  - Noise
  - Emissions

- Over Batteries
  - Energy Capacity
  - Recharge Time

Fuel cells have particular advantage in non-attainment areas with < 20% higher lifecycle cost than diesel engines
Fuel Cell Advantages over Electric Trains

- Fuel cell powered locomotives can roam
  - the system can grow without major commitments to new lines
  - unlike electrification, needs no critical traffic density to justify
  - Avoids either a totally new track or much interference with existing traffic while electrifying
  - Can begin with a few prototypes

- Power demand can avoid peak periods

- In 1998, Caltrain costed electrification of an existing 124-km commuter line at $376 M

- Pro-rated, the 32 km from Charlotte to Mooresville is $100 M
  - Should easily buy enough fuel-cell locomotives
To Summarize...

Fuel Cell locomotives potentially offer the best of two worlds

- Flexibility, efficiency, and low infrastructure cost of the diesel-electric locomotive
- Zero vehicle emissions, low noise, and oil-independence of the catenary electric locomotive
- Have particular advantage in non-attainment areas with < 20% higher lifecycle cost than diesel engines
Forza Rail Power Module (RPM)

- **Power**
  - 125 kW (net), 150 kW (gross)

- **Voltage**
  - 900V ±10% @ 0A to 600V ±10% @ 250A ±10% Unregulated

- **Compact**
  - 1.6m x 1.2m x 1.5m
  - 1500 kg, ~3 m³, 500 kg/m³

- **Rugged**
  - Railway duty
  - High Stacks Durability
  - Three axis shock loading

- **Field Serviceable**
  - Serviceable Fuel Cell Stacks
  - Automatic Valves, Controls
  - Pumps, Tanks, Filters
RPM Design and Safety

- **Design Features**
  - Solid, Low-Risk Design
  - Rugged, Compact, High-G Package
  - Proven XDS-900 Stacks
  - Proven PowerFlow High-Efficiency Recycle System
  - Totally Self-Contained

- **Two types of safety system trigger shutdown procedures**
  - **E-Stop** - Emergency shutdown that is immediate and results in all components returning to their non-powered/normal positions.
  - **Soft E-Stop** - Controlled system shutdown which executes the automated shutdown procedure.
Locomotive & Off-Road Experience - 17 kW

- 3.6 ton mining locomotive
- Nuvera’s 17 kW PEM fuel cell
- Successful operation in harsh conditions

Project is managed by Vehicle Projects, LLC

Our experience with locomotive applications is second to none
Locomotive & Off-Road Experience - 90 kW

Project is managed by Vehicle Projects, LLC

- 23 ton mine loader
- Nuvera’s 90 kW PEM fuel cell
- Testing to commence soon

Our experience with locomotive applications is second to none
Locomotive & Off-Road Experience - 150 kW

- One FORZA RPM delivered to Asia-Pacific in Jan 06
- Nuvera’s 150 kW PEM fuel cell
- FORZA exceeded contractual specs in power
Locomotive & Off-Road Experience - 1.2 MW

- 109 metric-ton-road-switcher
- 8 Nuvera’s FORZA RPM PEM fuel cell
- Project commence in 2007
NUVERA FUEL CELLS

EXPERIENCE The Future of Energy®