Clean Energy and Environment Research

Mechanical Engineering
University of Delaware
ME Faculty Conducting Clean Energy and Environmental Research

Fuel Cells, Batteries, and Supercapacitors

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Wind Energy

Advani  Burris  Prasad  Schwartz

Environment

Prasad  LP Wang
Center for Fuel Cell Research
Director: Ajay Prasad

1. PEM fuel cells
2. DMFC
3. SOFC
4. Hydroxide exchange membrane fuel cells

Materials

System-level

Solar Hydrogen Generation

Operational experience

Hydrogen storage

Batteries

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System-level

Materials

Hydrogen storage

Batteries

Solar Hydrogen Generation

Operational experience
Novel Materials for PEM Fuel Cells

- Novel composite membranes
- Tungsten Monocarbide catalyst
- Novel metallic GDL
- Design of flow channels using genetic algorithms

Durability Studies by Accelerated Stress Testing
- Humidity cycling
- Temperature cycling
- Freeze/thaw cycling of Nafion/MWCNT membrane

Processed Neutron Image

Water Thickness

- 2 mm
- 1.5 mm
- 1 mm
- 0.5 mm
- 0 mm
- 0 mm

Voltage, V

- 1.1
- 1.0
- 0.9
- 0.8
- 0.7
- 0.6
- 0.5
- 0.4
- 0.3
- 0.2
- 0.1

Current Density, A/cm²

- 0.0
- 0.2
- 0.4
- 0.6
- 0.8
- 1.0
- 1.2
- 1.4
- 1.6

Nafion 112

MWCNT/Nafion
Mechanics of Fuel Cell Membranes

Experimental Materials Characterization

Numerical in-situ models
And Results

Nano-structural models
### UD Fuel Cell Hybrid Bus Program (2005-present)

<table>
<thead>
<tr>
<th>Bus #</th>
<th>Size</th>
<th>Stack</th>
<th>Batteries</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22-ft</td>
<td>20 kW</td>
<td>Ni-Cad</td>
<td>2007</td>
</tr>
<tr>
<td>2</td>
<td>22-ft</td>
<td>40 kW</td>
<td>Ni-Cad</td>
<td>2009</td>
</tr>
<tr>
<td>3</td>
<td>40-ft</td>
<td>60 kW</td>
<td>Li-Ti</td>
<td>2014*</td>
</tr>
<tr>
<td>4</td>
<td>40-ft</td>
<td>80 kW</td>
<td>Li-Ti</td>
<td>2014*</td>
</tr>
</tbody>
</table>

*Expected delivery

Cell voltage monitoring is an important diagnostic tool for fuel cell stacks and battery systems

Variable-area Ejector for Hydrogen Recirculation:
- Simple PI pressure feedback control system
- No moving parts
- Very low power consumption

Patent pending
Solar Hydrogen by Thermochemical Cycles

Concentrated sunlight (2000 K)

Step 1: ZnO $\rightarrow$ Zn + $\frac{1}{2}$ O$_2$

Step 2: Zn + H$_2$O $\rightarrow$ ZnO + H$_2$

Tested at the Paul Scherrer Institute's high-flux solar simulator in Villigen, Switzerland (May 2012 and March 2013)

- 10 xenon-arc lamps delivering 50kW at a peak radiative flux of 11,000 suns.
H₂ Storage with Solid-State Materials

Effect of pitch

Effect of heat transfer coefficient

Internal cooling tube

Contours of H₂ storage

Non-dimensional pitch = 0.375
Filling time = 6 min

Mass of H₂ stored per unit volume of tank (g/cm³)

Convection heat transfer coefficient h (W/m²-K)

no aluminum foam is added
5% aluminum foam
10% aluminum foam

Non-dimensional pitch

Mass of H₂ stored per unit volume of tank (g/cm³)

Convection heat transfer coefficient h (W/m²-K)

no aluminum foam is added
5% aluminum foam
10% aluminum foam

Non-dimensional pitch

3 min charge

Contours of H₂ storage

Suresh Advani
Ajay Prasad
A new energy storage mechanism (Charge Close-Packed Model) is proposed to interpret anomalous capacitive behavior of energy density and ionic diffusion observed in one-body, all solid-state, sandwich-structured capacitor made from reduced graphene oxide films.

RGO – reduced graphene oxide; GO – graphene oxide
3D Resin Infusion To Simulate Wind Blade Manufacturing

The European Wind Energy Association (EWEA)

Gurit® - Break Down of a Wind Turbine Blade

The European Wind Energy Association (EWEA)

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Estimating Wind Turbine Drivetrain Loads

- Premature gearbox failure significantly increases cost of wind power
- It is unclear how non-ideal conditions affect drivetrain loads or reliability
- Smith et al. 2005: failure rates increase with wind shear at night
- Blade element theory: determine effect of wind shear on \textit{mean} $M_x$ and bearing load

\[ V(z) = a(b + z)^m \]

**Implications:**
Fatigue limit PLC-A = 184 kN (GRC standard)
Smith et al.: $m_{\text{day}} = 0.21$ and $m_{\text{night}} = 0.43$
$V_{\text{ave}} = 10 \text{ m/s} \rightarrow F = 81 \text{ kN}, T = 230 \text{ kNm} @ 22 \text{ RPM}$

\begin{align*}
\text{Day:} & \quad M_x = 254 \text{ kNm}, F_{\text{PLCA}} = 52 \text{ kN} < \text{ limit} \\
\text{Night:} & \quad M_x = 527 \text{ kNm}, F_{\text{PLCA}} = 219 \text{ kN} > \text{ limit}
\end{align*}

There is a direct and detrimental effect of wind shear on drivetrain reliability
Environmental Multiphase Flows

Approach: High-performance computing and analytical tools to understand complex multiscale fluid transport/transformation in the environment.

Specific applications:

- **Cloud physics and warm rain formation**: Effect of air turbulence on collision rates and collision efficiency of cloud droplets; impact on warm rain initiation.

- **Soil contamination and soil biodiversity**: Fate of nanoparticles released to the environment; how to model transport and retention of contaminants?

- **Industrial processing of multiphase wastes**: mixing, resuspension, sedimentation, non-Newtonian behavior, and scale-up of particle-laden flow in a controlled mixing vessel.