Research interests:
• Utilization of CO$_2$ for electrochemical synthesis of fuels at room temperature
• Alternative electrocatalysts supports (i.e. ceramics, functionalized carbon)
• High energy density electrodes for Li-ion batteries and supercapacitors

Techniques:
• Synthesis of high surface area materials
• Voltammetry, Electrochemical Impedance, CPR, chrono-methods
• XPS, XRD, RAMAN, FT-IR, TEM, SEM, TGA, MS, TPD
Controlling Microstructure and Surface Chemistry of Ordered Carbons for Fuel Cells and Supercapacitors

- Traditional carbon supports offer several near-ideal properties.
- Graphitized carbon blacks (CBs) have limited interaction with supported Pt – leading to large Pt particles and poor Pt stability.
- To yield high dispersion of Pt, CBs are oxidized in caustic environments – this gives very poor control over the types of functional groups and provides corrosion centers that limit long-term stability.
- Purposeful incorporation of adatoms into the carbon structure (i.e. N, S, P, B) has the potential to provide charge centers for strong-Pt bonding while not building in intrinsic instability.
- Recent work has shown that Pt catalysts with excellent dispersion (Pt < 2nm - left) even at high loading (50wt% Pt) with 10% surface N.
- Mass activities for un-optimized 50 wt% Pt/N-doped carbon > 120 mA/µg_Pt
- Can leverage the same techniques to increase the areal capacitance from ~ 10µF/cm² to > 25µF/cm²

William Mustain, University of Connecticut
Non-Carbon Supports for Enhanced ORR Activity and Stability of Pt

- Carbon-based supports offer several near-ideal properties
- Carbon has limited interaction with supported Pt – leading to large Pt particles and poor Pt stability; also difficult to enhance the intrinsic activity of Pt to avoid alloying
- Carbon corrosion is thermodynamically favored at ORR relevant potentials and kinetically facile during startup/shutdown
- Non-carbon supports have been shown to enhance the activity of Pt by electron transfer – allowing the Pt oxidation potential to be raised (i.e. Pt/WC)
- Non-carbon supports can also; 2) impose Pt geometry & preferential faceting (i.e. Pt/ITO – right) for significantly higher activity than Pt/C.
- There is still a need to enhance the stability of ceramic supports to avoid oxidation cycles and structural deformation.
- MEA testing is also needed

Pt/ITO has Excellent ORR Pt activity and NO measurable performance loss over 1000 cycles

<table>
<thead>
<tr>
<th>DOE 2015 Targets</th>
<th>Pt/ITO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Activity (mA/cm²)</td>
<td>0.72</td>
</tr>
<tr>
<td>Mass Activity (mA/μg Pt)</td>
<td>0.44</td>
</tr>
</tbody>
</table>

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Electrochemical Recovery and Utilization of CO₂ for the Room Temperature Synthesis of Fuels

- Methane steam reforming (MSR) to syngas is one of the most important chemical processes – leading precursor for methanol, formaldehyde and H₂.
- MSR is energy intense & large CO₂ producer
- Oxidation of CH₄ (8e⁻) to CO (2e⁻), then reduction to desired product (i.e. CH₃OH, 6e⁻) wastes energy and adds system complexity.

- Room T carbonate electrochemical devices (left) offer a new pathway to oxidize methane to oxygenates and fuels. To date, mostly small oxygenates have been synthesized (shown above).
- Novel metal-metal oxide bifunctional are being devised to destabilize the C-H bond with much lower energy at room T and atmospheric pressure.
- Work to understand the atomic-level mechanism, controlling product selectivity and scale-up remains.

William Mustain, University of Connecticut
Creation & Manipulation Of An Artificial Termite Gut Through Control Of The Microenvironment

- Currently, efforts to convert wooden materials limited by the inability of synthetic (human) systems to design reactors to process lignocellulosic material

- What is the most efficient known system?
  - Termite hindgut

William Mustain, University of Connecticut
Materials Genomics

- Materials development and implementation are currently very linear processes, which makes the process very time intensive.
- There does not exist a sufficient understanding of the structure-property and materials-property relationships to make a truly predictive materials design approach.
- As a result, scientists and engineers rely on trial-and-error approaches for materials development.
- Our goal is to a-priori predict what to make, what structure it should have and what the best approach is to achieve the desired chemistry-structure relationship.