# Concept paper

* impact -- disruptive
* figure
* methanol economy better than hydrogen
* incremental market introduction
* target energy density (volumetric & gravimetric)
* address CO2

## Task assignment

* manufacturing: PGI
* battery development: Chunmei
* Stabilize Pt:Ru catalyst: Steve
* Methanol concentration/crossover (MEA): Branden

## Outline

Opening Line Combining energy generation and storage decouples power from energy.  
Next generation technologies, from portable electronics to transportation to development of the next generation smart grid are impeded by insufficient power systems.

A hybrid battery-fuel cell power system joins the energy density and generation properties of a fuel cell with the power response of batteries.

Combining energy generation and energy storage results in a capacity multiplier.

Combining a fuel cell and battery into a hybrid power system leverages the strengths of the one in support of the weaknesses of the other.

The choice of fuel cell and battery technologies are an optimization that requires careful consideration of application-specific demands.

This project will advance the energy generation and energy storage components, and combine these into a power device that will be immediately disruptive in low-to-mid-level portable power applications. Developments in this space will likely lead to revolutionary, near-term implications in the transportation (EV) market.

### Fuel Cell

There are many fuel cell technologies available: hydrogen, direct alcohol, molten carbonate, solid oxide.

The scalability of fuel cells decouples power and energy capacity.

* Type of fuel cell
  + low T: hydrogen, direct methanol, set fuel type, but more efficient for both small scale and intermittent applications.
  + high T: molten carbonate, solid oxide, flexible fuel, but inefficient for small scale and intermittent applications.
* Hydrogen vs. methanol
  + Methanol and hydrogen have comparable energy capacities. [(Arico2009)](http://books.google.com/books?hl=en&lr=&id=xHsJJieZlHwC&oi=fnd&pg=PA1&dq=Direct+Methanol+Fuel+Cells+:+History+,+Status+and+Perspectives&ots=iDVDBBaEl5&sig=BtotK4fVYetE5w_cc2AigTz2Dnk)

|  |  |  |
| --- | --- | --- |
| **Fuel** | **Energy Density (Wh/L)** | **Specific Energy (Wh/kg)** |
| Methanol | 3228 - 3976 | 5390 - 7122 |
| hydrogen (metal hydride) | 1532 - 2339 | 374 - 635 |
| hydrogen (cryogenic liquid) | 1839 - 2317 | 25,316 - 33,172 |

* + Although liquid hydrogen provides the largest gravimetric capacity, this is overshadowed by the balance of plant structures required for cryogenic storage (reference?). Methanol has a 75.5% higher energy density than cryogenic hydrogen and a negligible intrinsic requirement for fuel storage.
  + Existing manufacturing, distribution, and point-of-sale infrastructure can be easily, and incrementally, converted from gasoline/diesel to methanol. Hydrogen could not.
  + Currently, (fraction?) methanol is produced by steam reforming methane (reference?). However unlike other higher order alcohols, technologies exist at a technological readiness level of XX for the commercial production of methanol from biomass. Thus, the use of methanol would result in the closed cycle production, distribution, and reclamation of carbon, resulting in a carbon-neutral fuel source.

For these reasons, this work will focus on the integration of direct methanol fuel cells as the power generator.

### Batteries

There are many energy storage options: lithium ion, magnesium ion, redox flow, supercapacitors. (Expand discussion on the down selection from these to lithium ion batteries.)

With volumetric energy densities between 256 and 394 Wh/L and specific energies between 86 and 147 Wh/kg,[(Arico2009)](http://books.google.com/books?hl=en&lr=&id=xHsJJieZlHwC&oi=fnd&pg=PA1&dq=Direct+Methanol+Fuel+Cells+:+History+,+Status+and+Perspectives&ots=iDVDBBaEl5&sig=BtotK4fVYetE5w_cc2AigTz2Dnk) lithium ion batteries have energy capacities and kinetics sufficient to handle fluctuations in power demands.

The use of liquid electrolytes in lithium ion battery chemistries increases the complexity of battery design and are involved in numerous unsafe redox reactions, particularly at overcharged and undercharged conditions. Solid state lithium ion batteries do not suffer from operational limitations that plague these chemistries.

A hybrid power systems ensures the battery remain within the broad window for optimal battery performance.

For these reasons, this work will focus on integration of solid state lithium ion batteries as the power storage medium.

### Team

Our interdisciplinary team brings in research and manufacturing expertise from industry, from academia, and from the national laboratory system.

Our strengths: characterization, experimental synthesis, system modeling, manufacturing.

## References

(Arico2009) Aricò, A., Baglio, V. & Antonucci, V. in Electrocatal. Direct Methanol Fuel Cells 1-78 (2009)

# Notes

## Benefits

A hybrid system allows the strengths of one component to balance the weaknesses of the other, e.g.

1. developments in energy storage (battery), energy production (fuel cell), methanol production and distribution -- and to a lesser degree, DC power electronics -- provide independent pathways to system improvement and incorporation.
2. methanol distribution can be incorporated into existing infrastructure with minimal effort. This allows methanol production and distribution to be ramped up incrementally.

### DMFC

* extensible energy capacity
* high energy density (volumetric and gravimetric) than lithium ion hydrogen.
* existing potential for a closed carbon cycle fuel
* excellent scalability
* excellent cell-to-cell consistency

### Batt

* rapid power response (kinetics)
* medium capacity (SC < Batt < DMFC)

Several technical challenges prevent immediate implementation of a HBFC...

## Technical Challenges

### DMFC

* poor kinetics
* catalyst stability (anode)
* crossover current
  + electromigration
  + diffusion
* polarization
  + Ohmic
  + electrochemical
  + catalytic
* H2O management
* DC electronics require V≥1 V

### Battery

* limited energy storage capacity
* poor operating range (T, state of charge -- charge window)