DEFENCE R&D DÉFENSE

Materials Issues for H_2 R&D in Canada

Defence R&D Canada Atlantic

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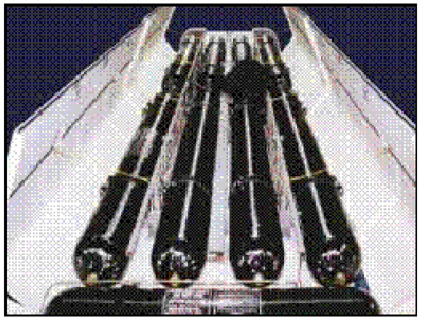
Outline

- Canadian Interests
- History
- R&D&D Programs
- Research Networks
- Materials Research Projects

Canadian Interests

- **H_2 Production, Delivery, and Utilization**
  - Electrolysis, gasification (biomass, carbon (CO_2 neutral)), novel methods (process by-product, etc)
  - H_2 ICE

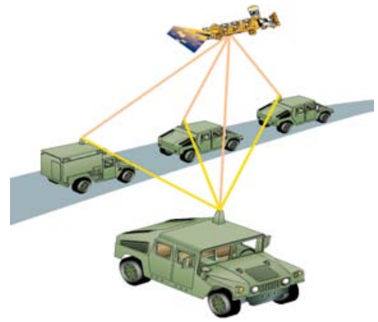


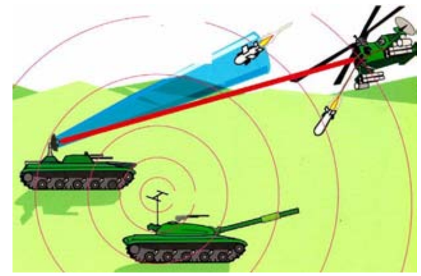
- **Fuel Cells**
  - PEM, DMFC, SOFC, Alkaline
  - Stack and system development
  - Manufacturing
  - Transportation, stationary,
  - portable, and mobile

- **Codes and Standards**

Range of Power Source Applications

Forces Need Wide Range of Power Systems





Battlefield Awareness

C^4ISR

Directed Energy Weapons
Active Protection

10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7

Milliwatt … Megawatt

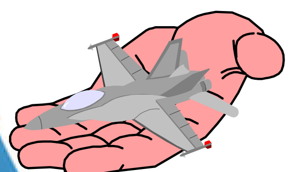
MEMS

Portable Battery Packs
Soldier Systems

Tactical Power
UAV

LAV

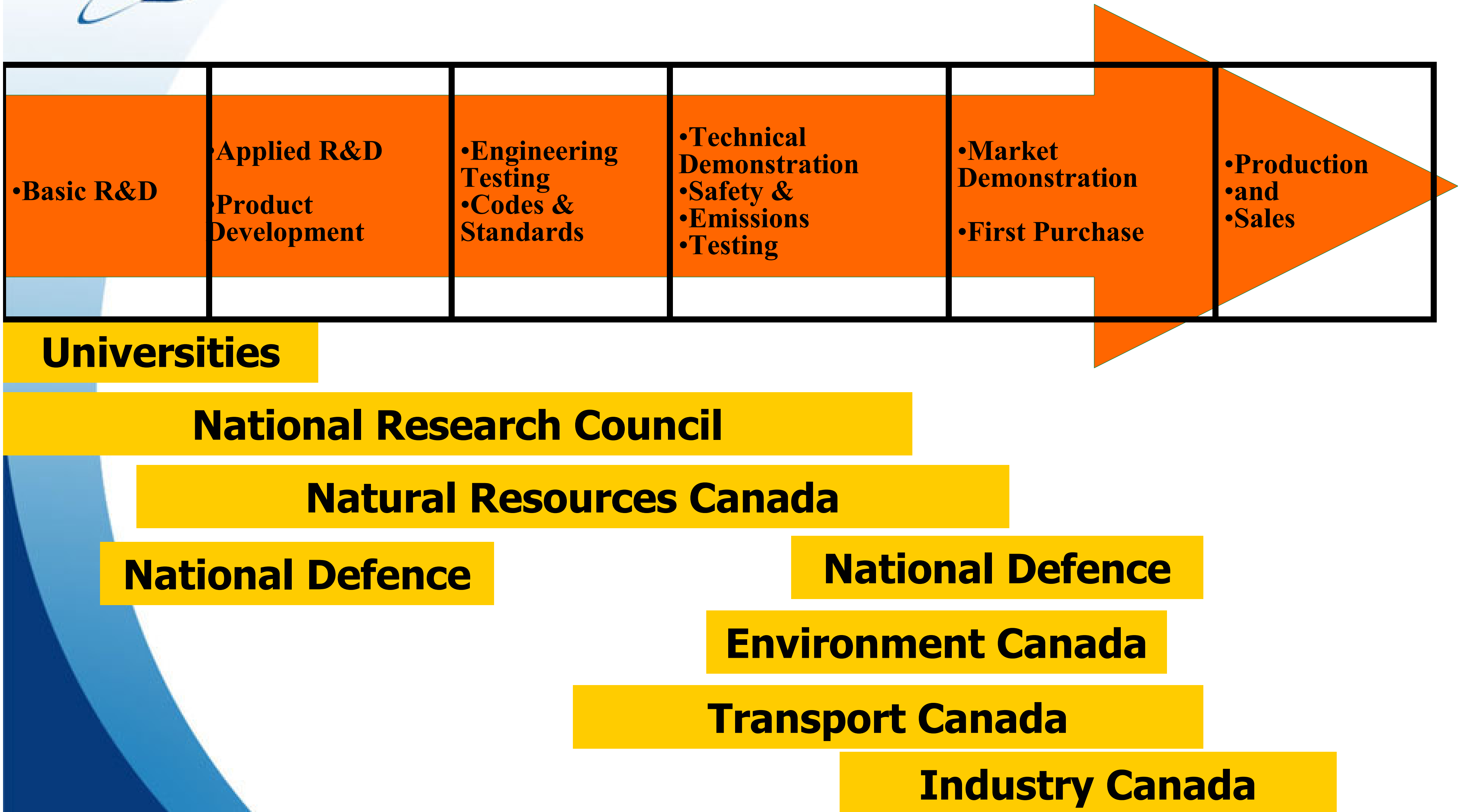
Relocatable Temp Camps
Ships & Main Battle Tank



Canada H_2 & FC History

- 1982 first contract for Ballard Power Systems
- Through Government-industry partnerships
- fuel cell transit bus 1997
- Ford P2000 engine, the first prototype fuel cell engine for the Ford Motor Company
- Vancouver Fuel Cell Vehicle Project - demonstration of fuel cell cars in real-world fleet applications 2005- 2008
- 10,000 psi (700-bar) H_2 fuelling station
- 250 kw pre-commercial SOFC CHP system

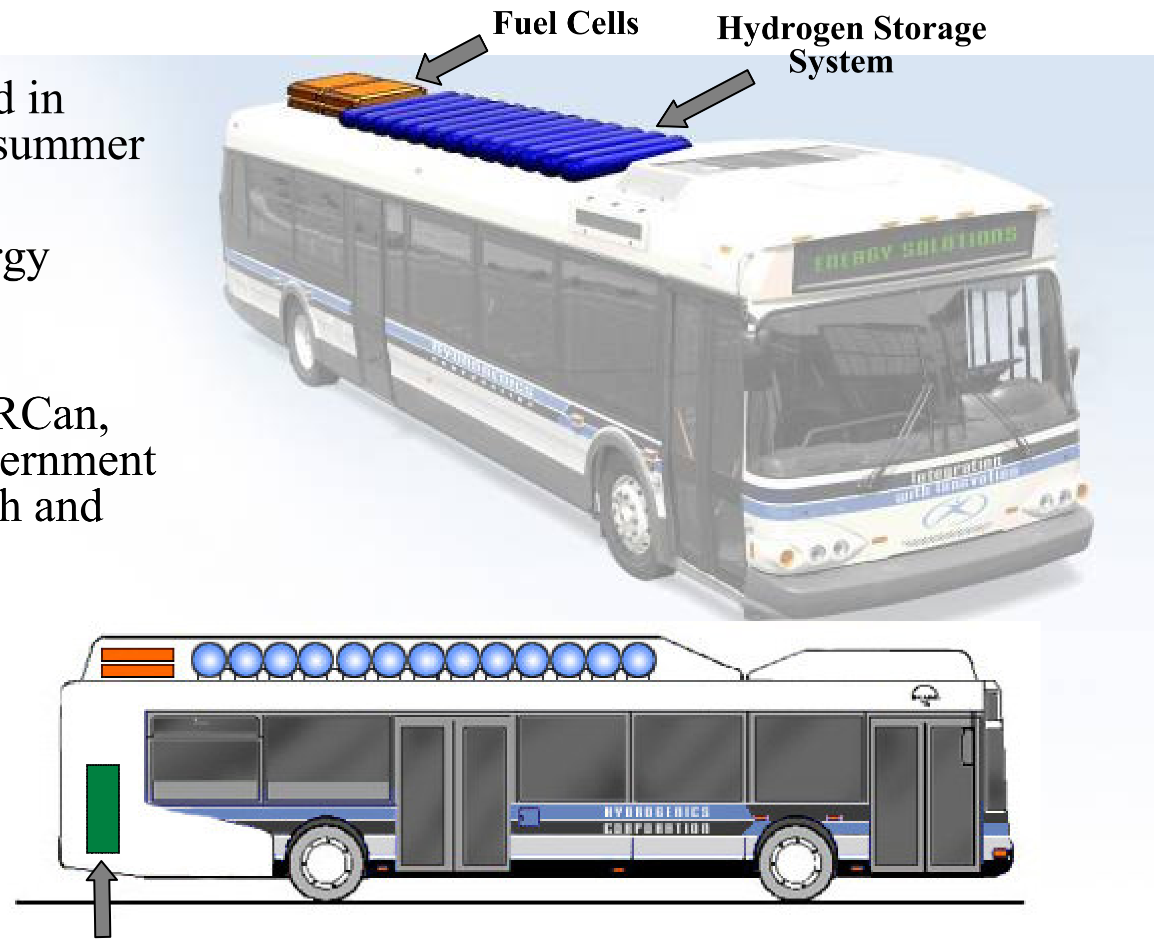
Canadian Programs



Hydrogen and Fuel Cell Demonstration

Hybrid Fuel Cell / Ultra-capacitor Transit Bus

- Successfully demonstrated in Winnipeg, Manitoba last summer
- 25% improvement in energy efficiency
- Partners: Hydrogenics, NRCan, Dynetek, New Flyer, Government of Manitoba, ISE Research and Maxwell Technologies



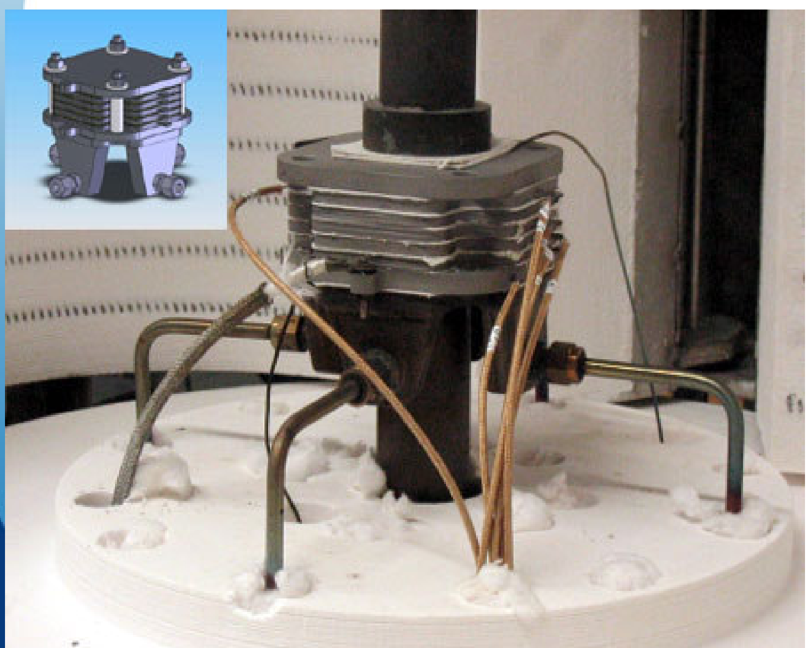
Canadian Networks

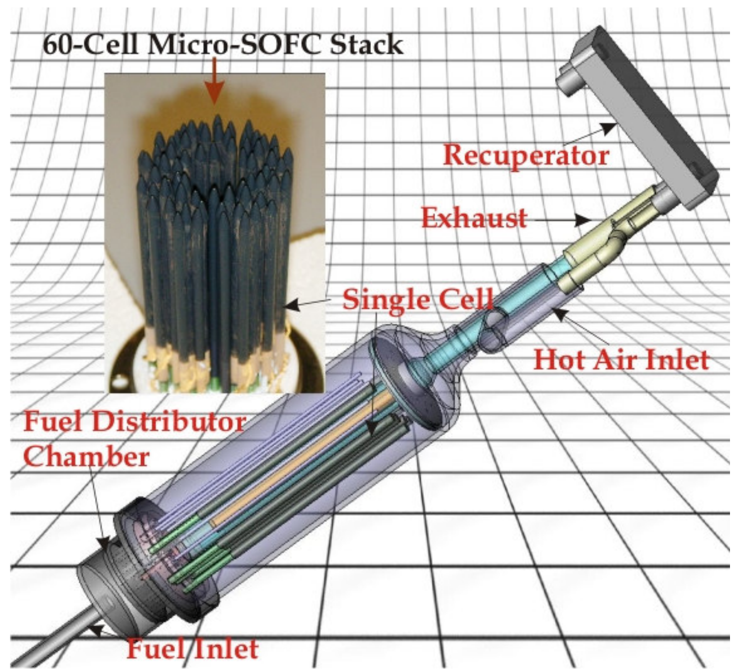
- **International Networks**
  - Government (NRC, NRCan), industry, and university participation
  - IPHE, IEA, HIA, AFCIA, BSIA
- **Academic Networks**
  - Funded by NSERC
  - Hydrogen, PEMFC, SOFC,
  - FCRC, OFCRIN, SOFC Canada, WCFCI. PEMFC Network, CANH2
- **SOFC Canada**
  - Four themes: Fuel processing, C/S tolerant anodes, system integration, cell substrates
- **FCRC- OFCRIN**
  - Performance, reliability, &durability, reduced costs through material design
  - Five Themes: Fuel Storage & supply, reliability & durability, system modelling, materials development, systems analysis

SOFC Canada

Metal-supported Planar SOFC

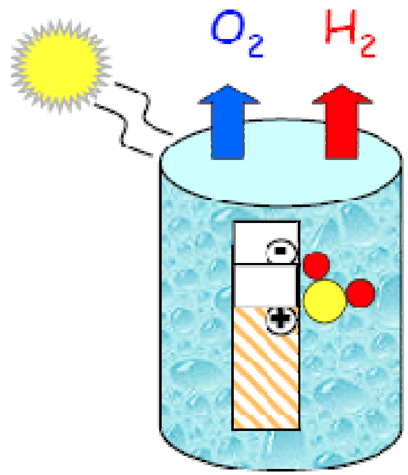
Porous electrolyte support Micro-tubular SOFC)





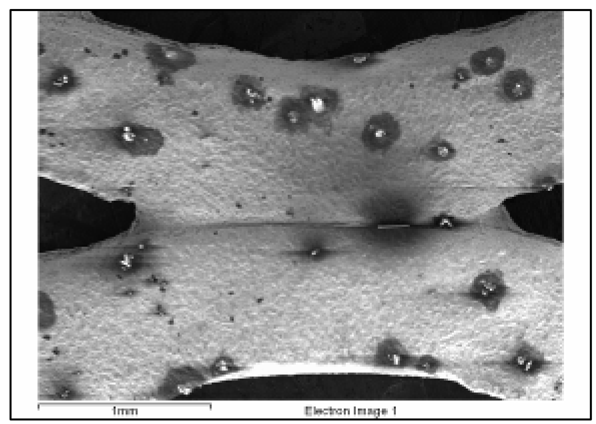
Hydrogen Production Materials Issues

- **Splitting H_2O**

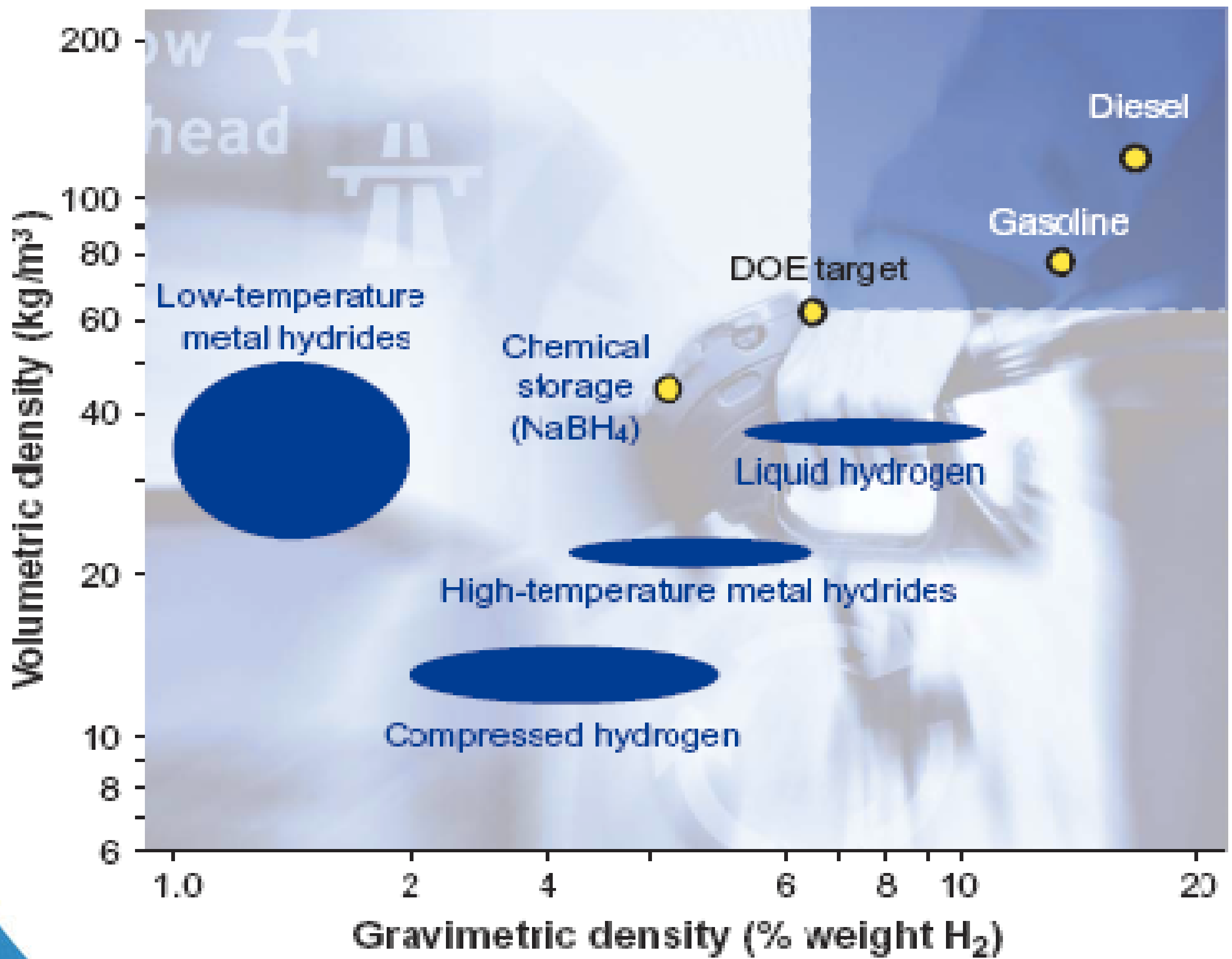


Solar electrolysis
Nano structured high surface
Band gap
Dye sensitized

- **Electrolysis**
  - Increased stability & durability of cathode in alkaline media
  - Increase energy density to 855ma/cm2 at 1.80 v and 70 C



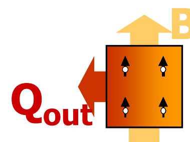
Hydrogen Storage Today: Gas and Liquid



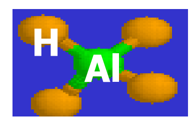
Hydrogen Storage Materials Issues

- **700 Bar Compressed H_2**
  - Al carbon fibre re-inforced – weight and cost issues – Dynetek
  - 1kg/L, 19,000 fill cycles

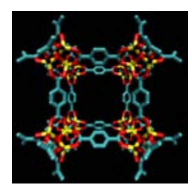
- **Magnetic Refridgerization**

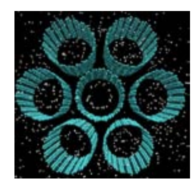


- **Complex Hydrides & metal Hydrides**



- **Nanostructured Materials**

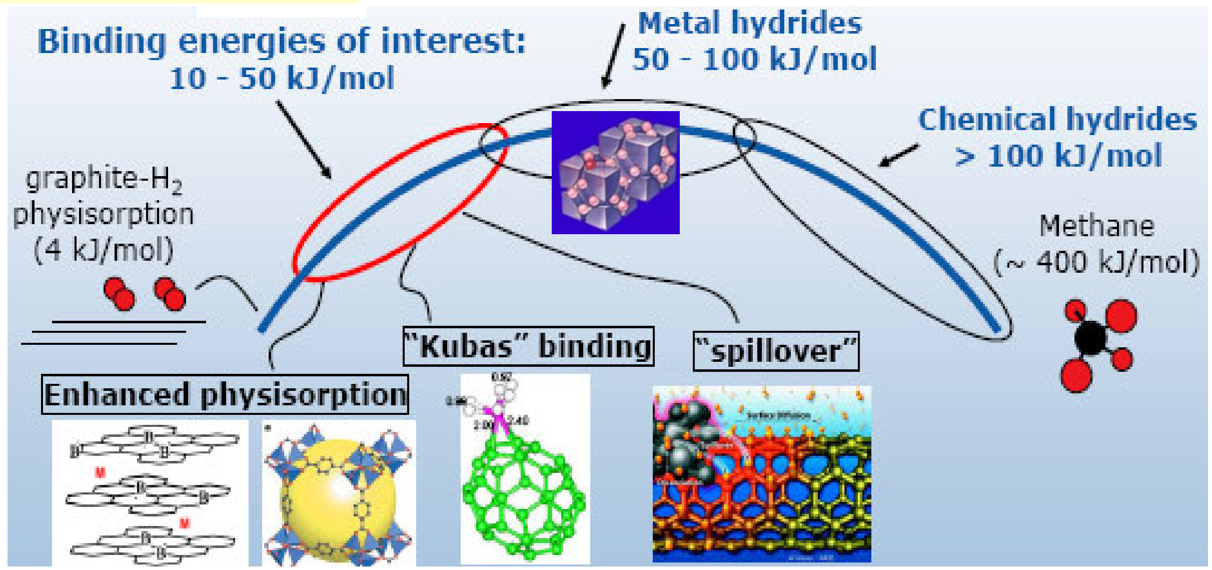




Continuum of Hydrogen Binding Energies

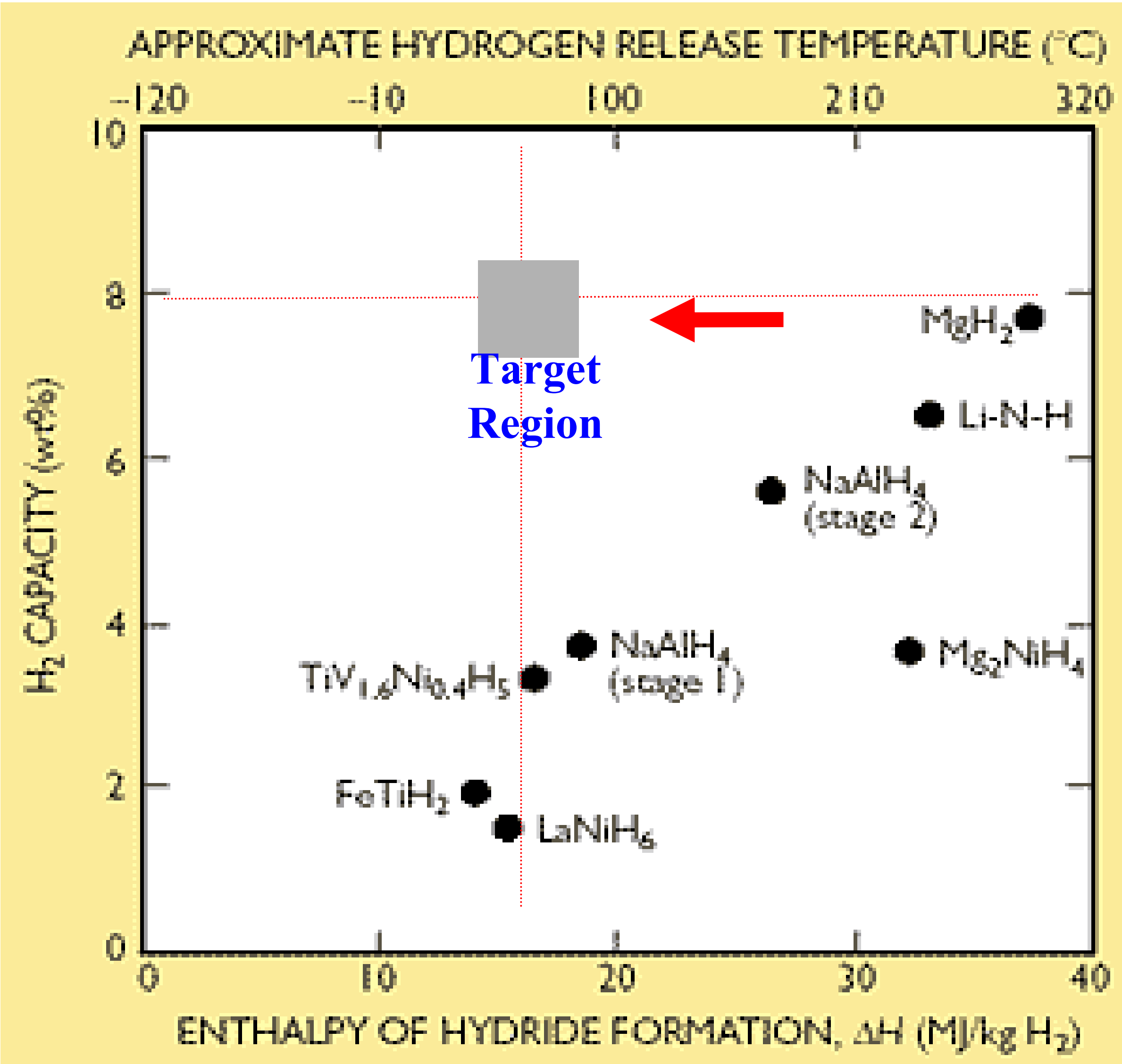
For reversible systems, equilibrium between gas and solid is given by:

$$P = \exp(-\Delta H/RT + \Delta S/R)$$



- Want lower enthalpy or higher temperature
- Increase rate of desorption

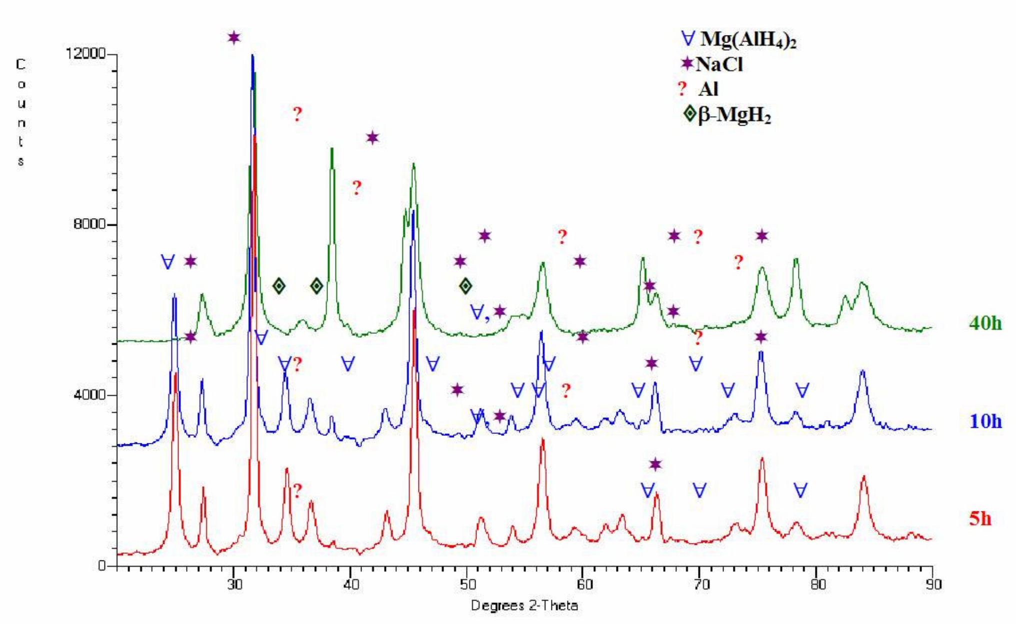
Issues with hydride storage



- Materials investigated do not meet goals
  - Lower enthalpy by destabilization
  - Use nano-catalysts to increase rates of H_2 release
  - MgH_2 nanocomposites with $LiAlH_4$

Mechanosynthesis of $Mg(AlH_4)_2$

$$MgCl_2 + NaAlH_4 \xrightarrow{1} Mg(Al^{3+}H^{-}_4)_2 \cdot NaCl \xrightarrow{2} MgH_2 + Al^0 + 3H^0_2$$



Theoretical 9% except for salt*
Irreversible ca. 3 wt% H @ 150 C

stage 1: **synthesis** via metathesis reaction

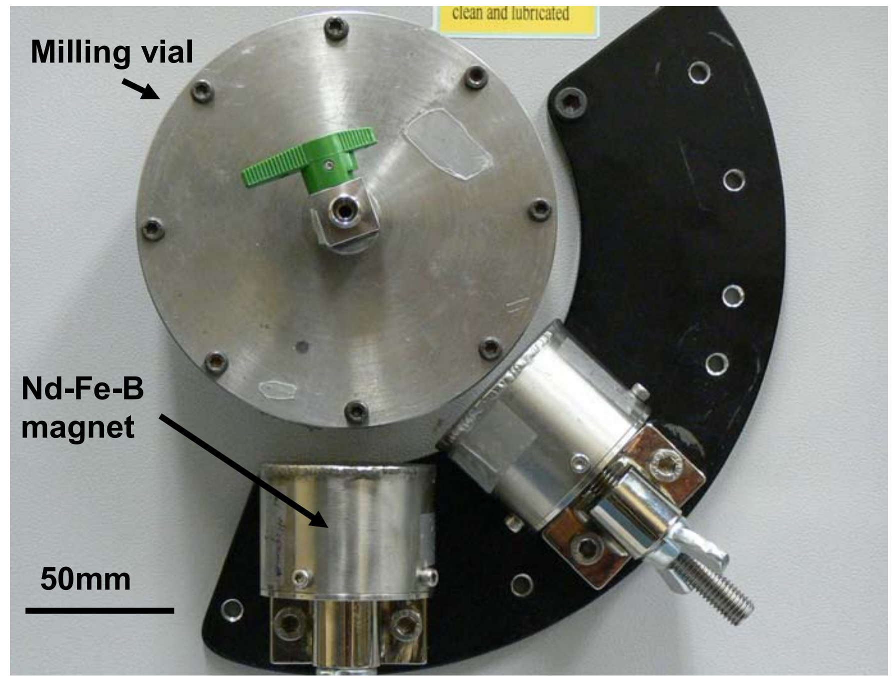
Stage 2: **decomposition** via redox disproportionation

Hydrogen Ball Milling

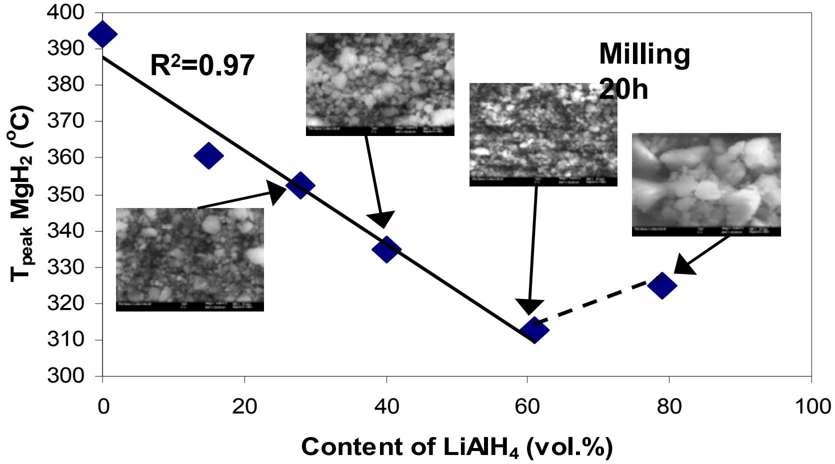
•Controlled mechanical modes of milling : Impact or Shear Mode

•Sequential supply of hydrogen gas

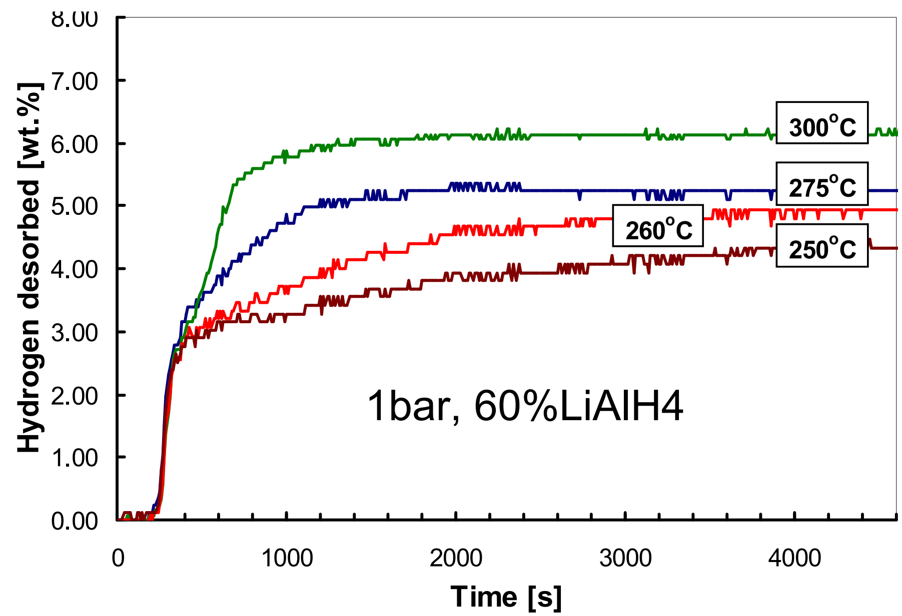
•Angular positions of Nd-Fe-B supermagnets under shear mode. The angular positions of external magnets can be changed for each of the controlled modes of milling.



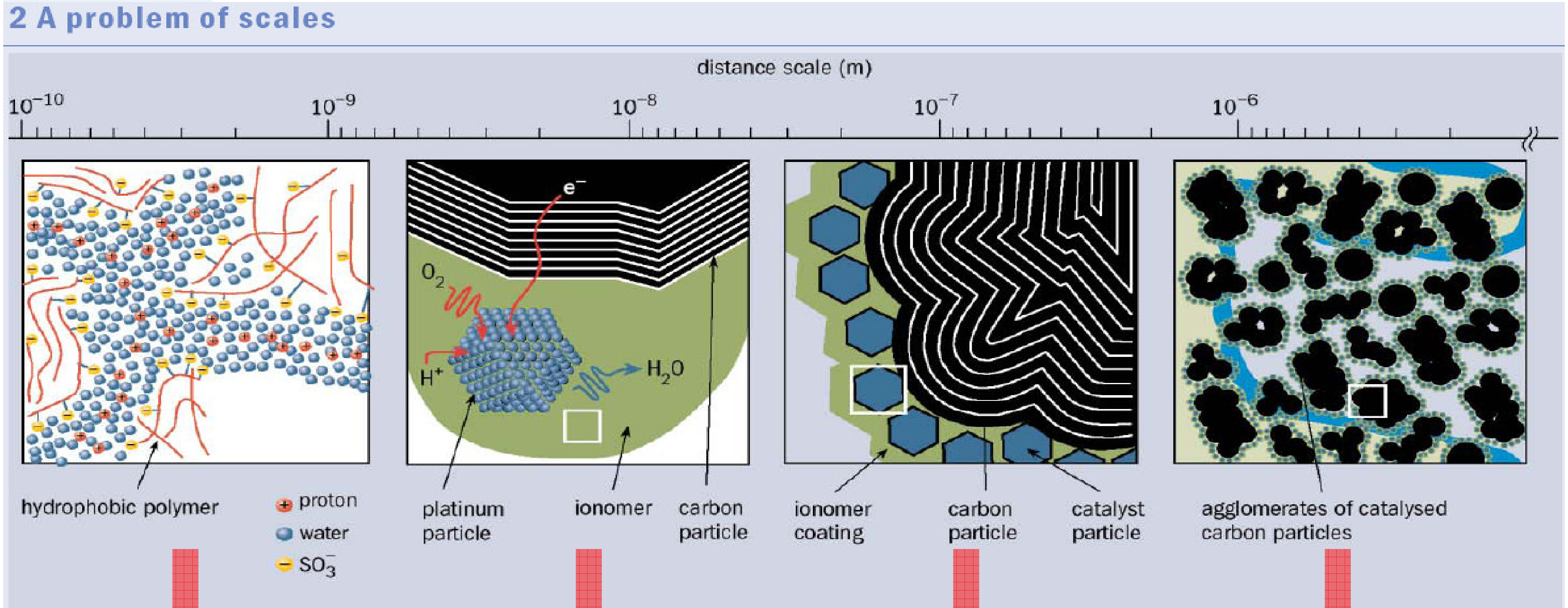
$MgH_2/LiAlH_4$ nanocomposite



MgH_2 destabilization by chemical hydride



Challenges for Materials and Operation PEMFC



Molecular scale, nanoscale

proton conductors: Higher Temperature

electrocatalysis: Pt dissolution

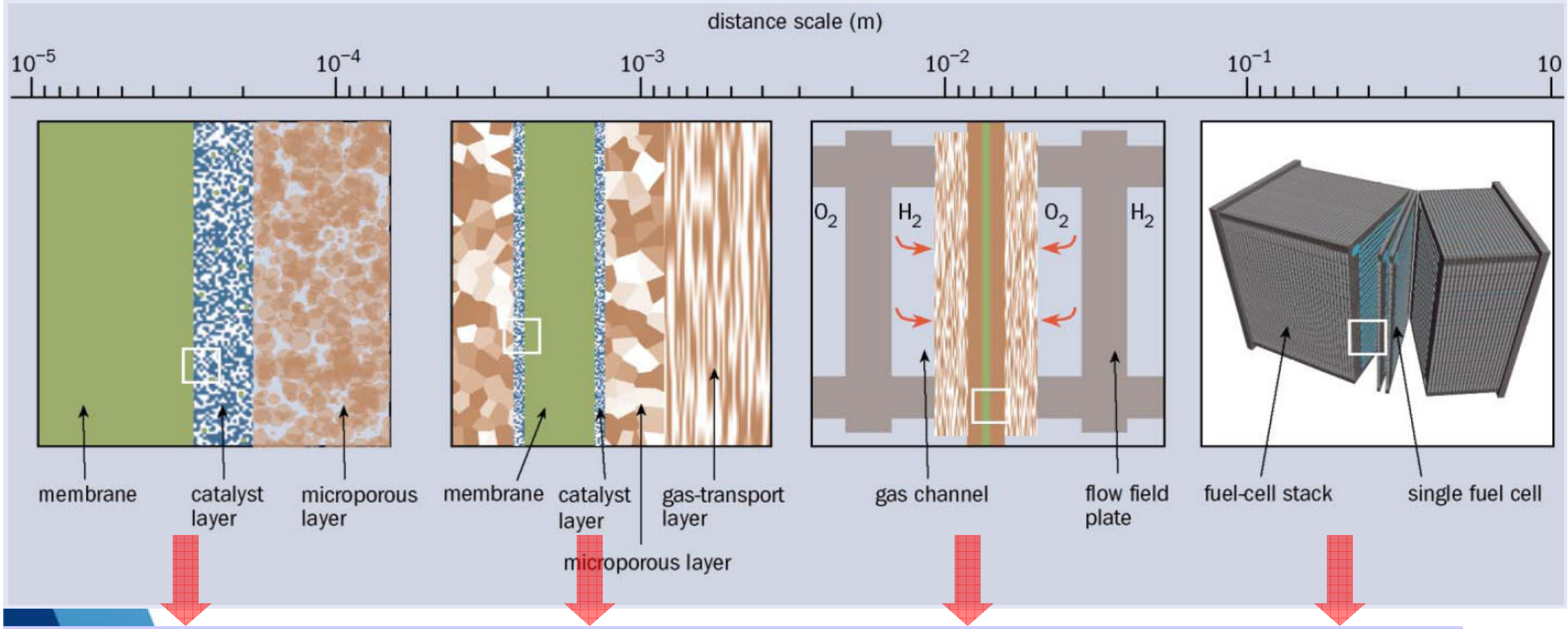
Mesoscale

Carbon support: stability

Macroscale

effective properties: Active surface area

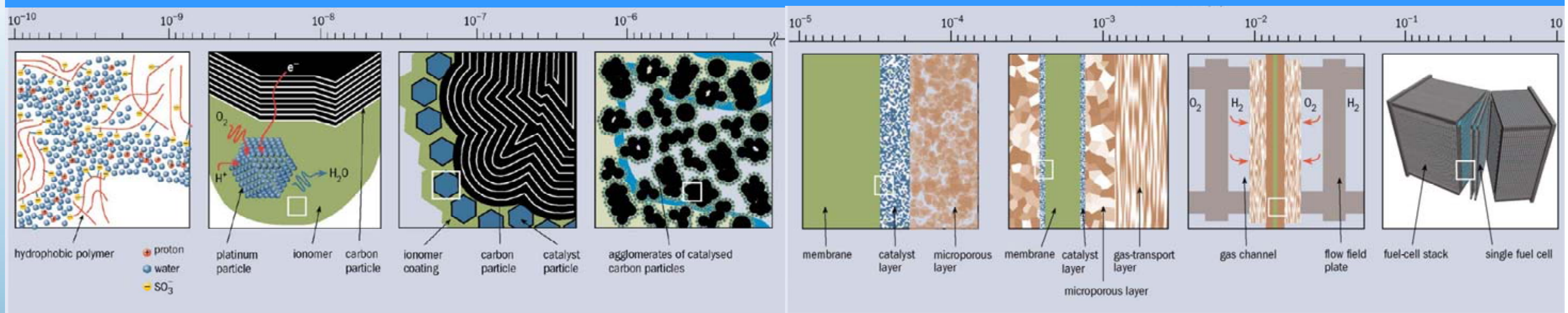
Challenges for Materials and Operation PEMFC



Fabrication and optimization of MEAs. Engineering of Cells & Stacks

MEAs: High temp membrane	Carbon felt stability	Water management	Fuel: gasification purification

Design Challenge: Multiple Scales



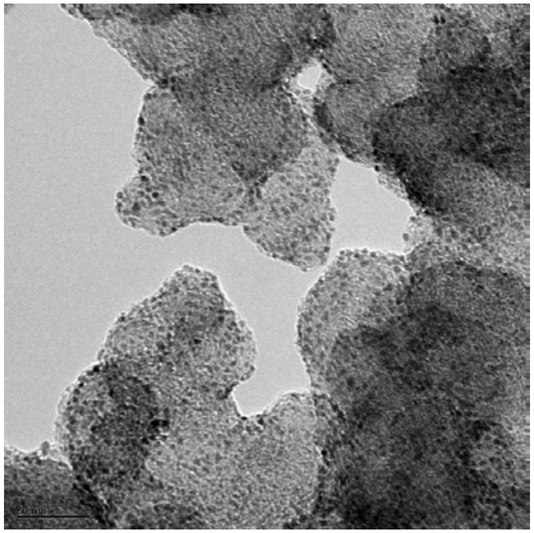
> 10 orders of magnitude,

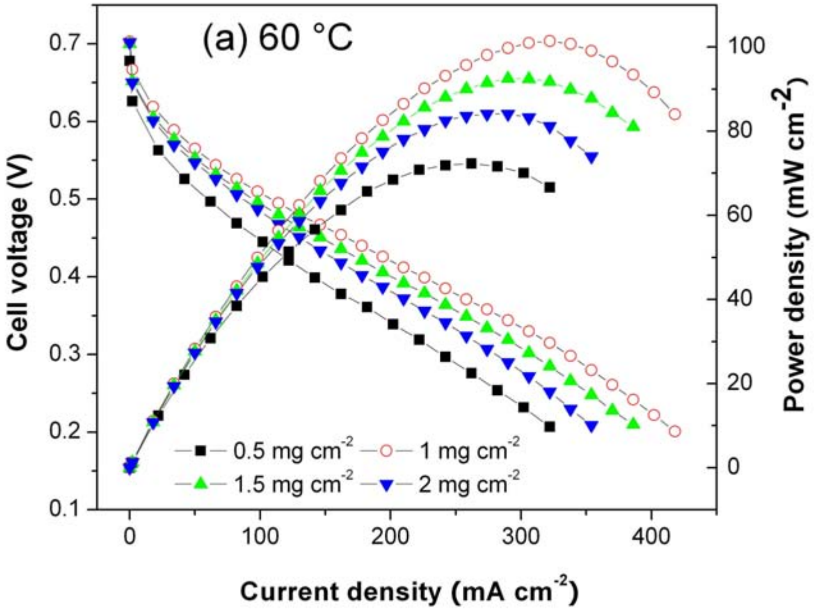
Multidisciplinary materials approach

- High temperature PEMFC for Transportation (>100 C)
  - Durable, Low cost materials
  - Membrane, low-humidity proton conductors
  - Less Pt, CO tolerance, non Pt
  - Low cost bipolar plates

Controlled Synthesis of Bimetallic Nanoparticles for DMFC

Modified polyol method using small stabilizers





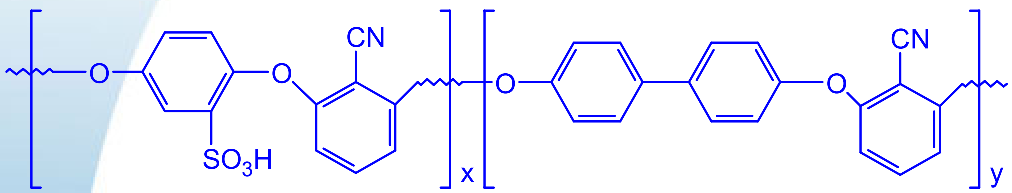
•Relative high performance for "low" noble metal catalyst loadings for DMFCs (<3mg cm^{-2})

Max. 100 mW cm^{-2},

•~6 times less catalyst than reported

Polynitrile PEM Materials from Commercial Monomers

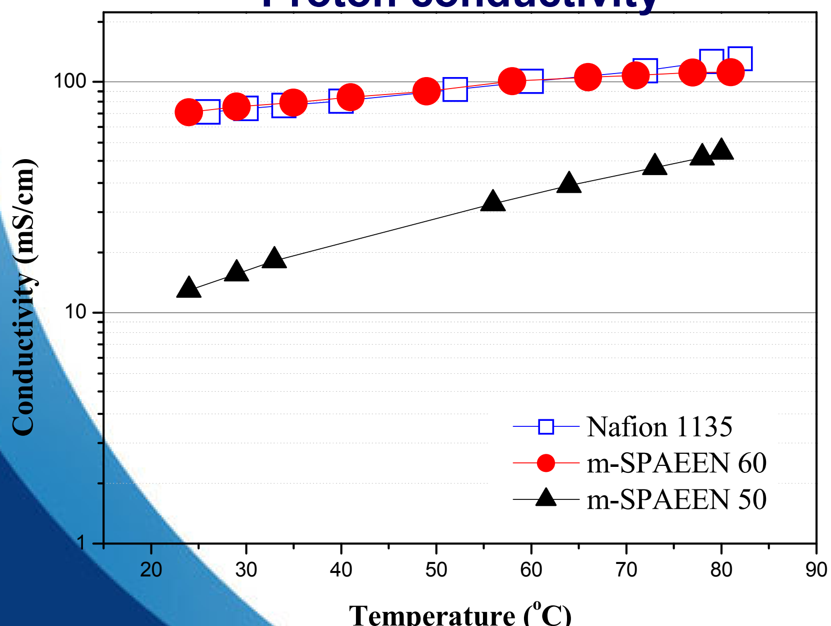
- Inexpensive
- High proton conductivity
- Low dimensional swelling
- Good catalyst adhesion
- Excellent cell performance
- Stable under MEA conditions

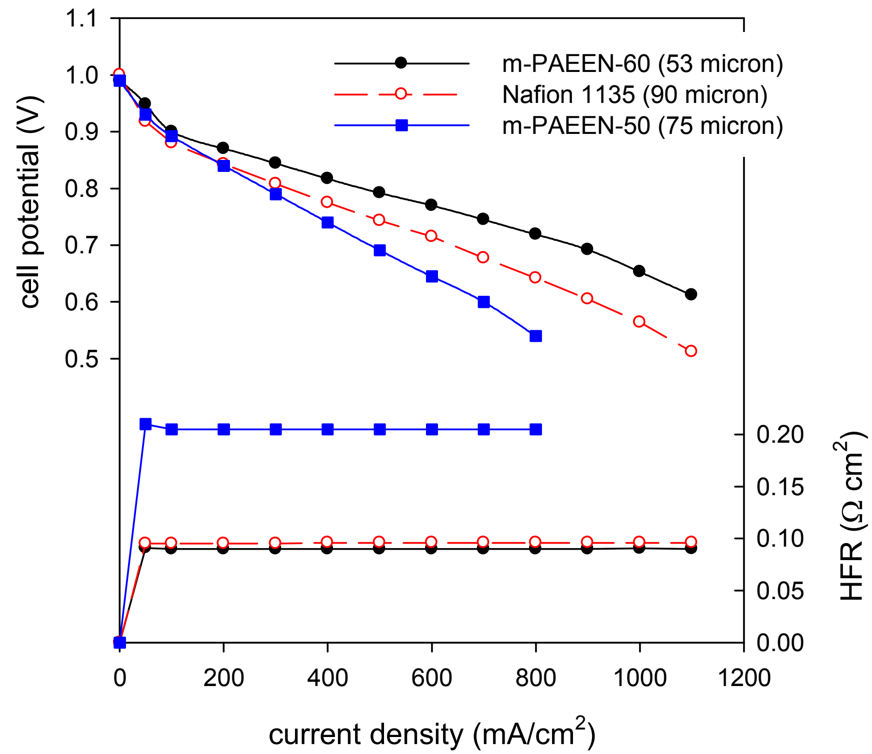


□ m-SPAEEN-60. Swelling 17% @ 80°C

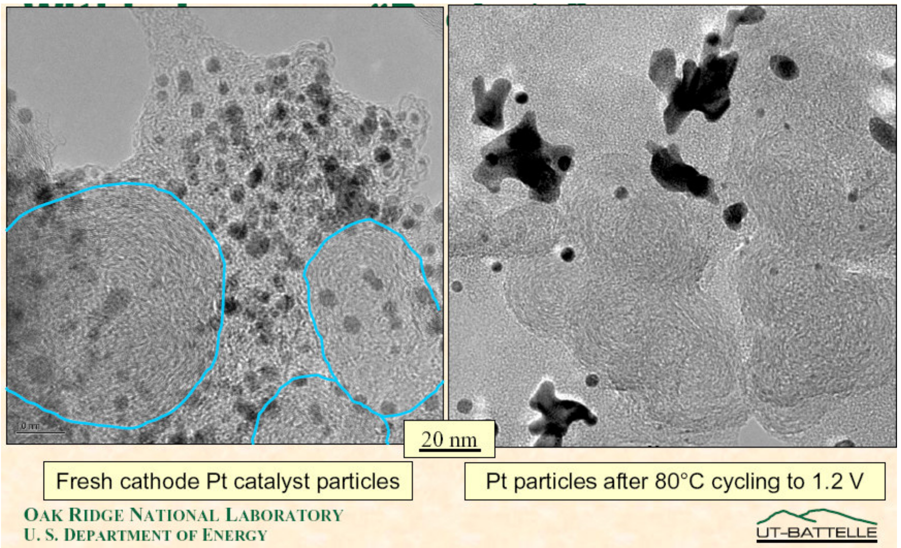
● Nafion. Swelling 16-20% @ 80°C

Proton conductivity





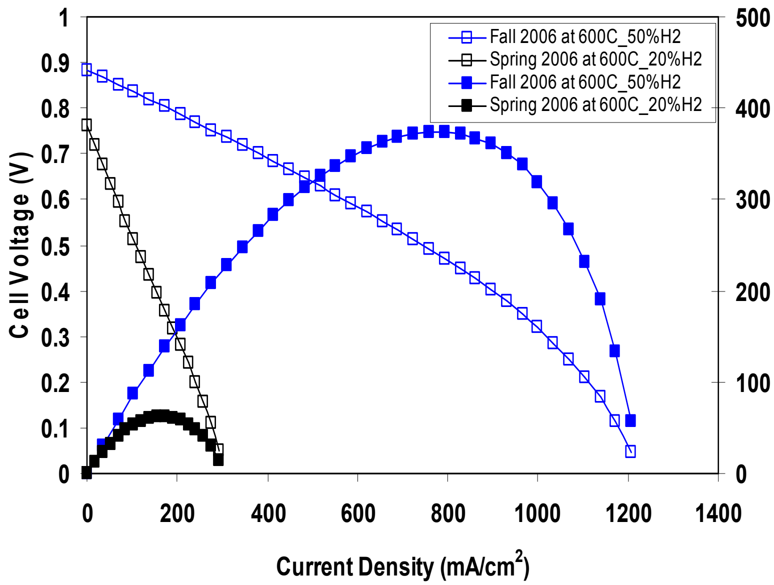
PEMFC Cathode Degradation



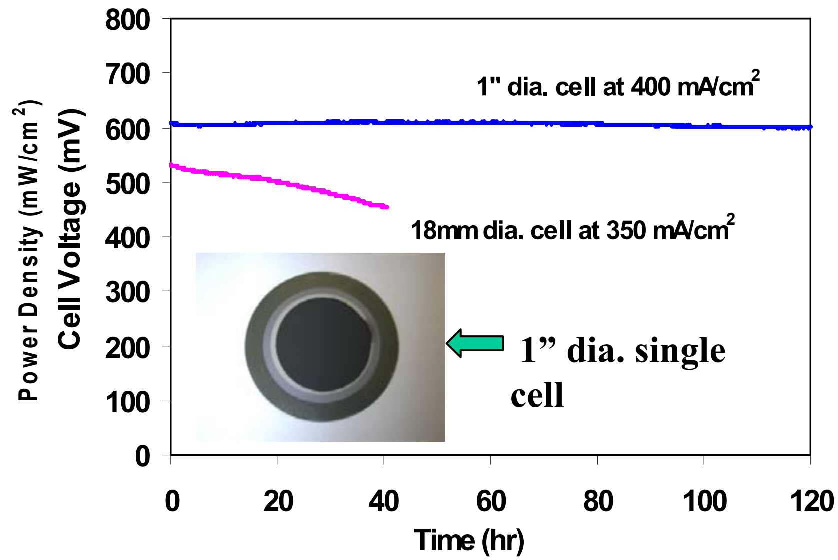
- High cathode voltage cycling causing Pt dissolution and recrystalization

Reduced Temperature SOFC

- intermediate temperature metal supported SOFCs



metal supported cell of SSC//SDC/ScSZ//Ni-SDC//SS substrate (H_2 in Ar/air)



Degradation of metal supported cells of LSCF//GDC//Ni-SDC//SS substrate at 600 °C (H_2 in Ar/air)

Canadian Interests

- **H_2 Production, Storage, and Delivery**
  - Electrolysis- more efficient electrocatalysts
  - Gasification- gasifier materials, carbon capture materials
  - Materials for thermo-nuclear water splitting cycles
  - Materials that provide sufficient storage for automobiles

- **Fuel Cells**
  - PEM, DMFC- Hybrids – electrocatalysts (low Pt, & non-noble), proton conducting membrane materials. battery materials
  - SOFC- materials for low temperature operation
  - DCFC (MCFC)- stable cathode materials