DEFENCE R&D DÉFENSE

Materials Issues for H_2 R&D in Canada

Defence R&D Canada Atlantic

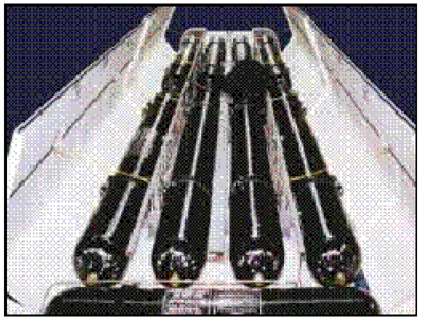
Rod McMillan, NRC

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

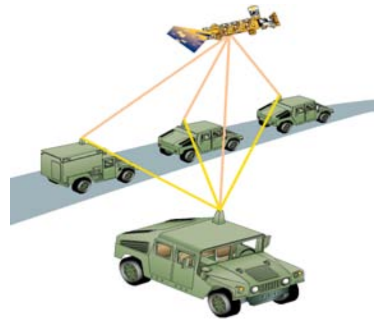


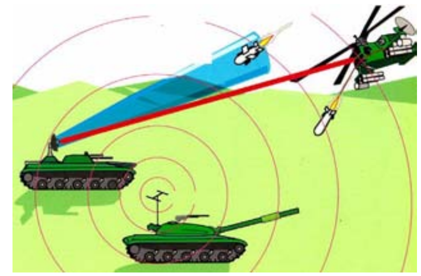
- **Fuel Cells**
  - PEM, DMFC, SOFC, Alkaline
  - Stack and system development
  - Manufacturing
  - Transportation, stationary,
  - portable, and mobile

- **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

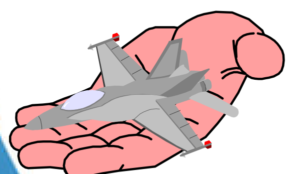
MEMS

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

•Basic R&D	•Applied R&D •Product Development	•Engineering Testing •Codes & Standards	•Technical Demonstration •Safety & •Emissions •Testing	•Market Demonstration •First Purchase	•Production •and •Sales

Universities

National Research Council

Natural Resources Canada

National Defence

National Defence

Environment Canada

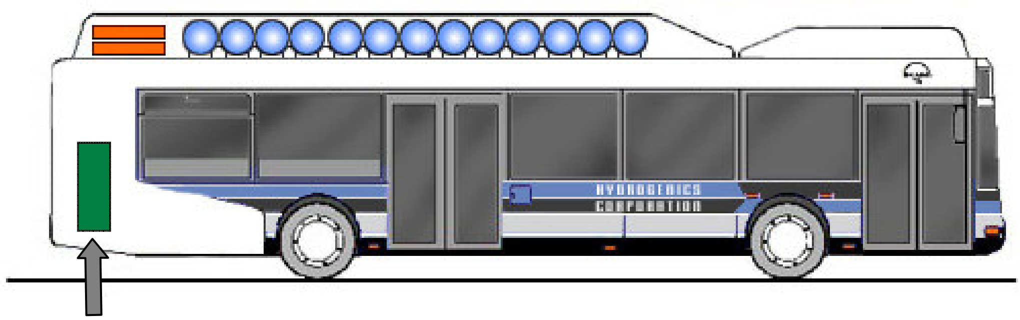
Transport Canada

Industry Canada

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

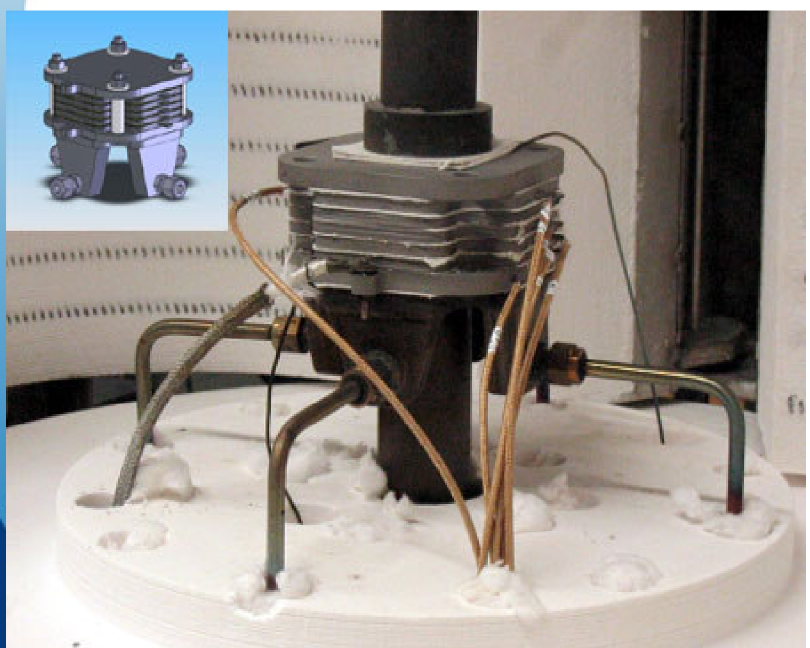


Canadian Networks

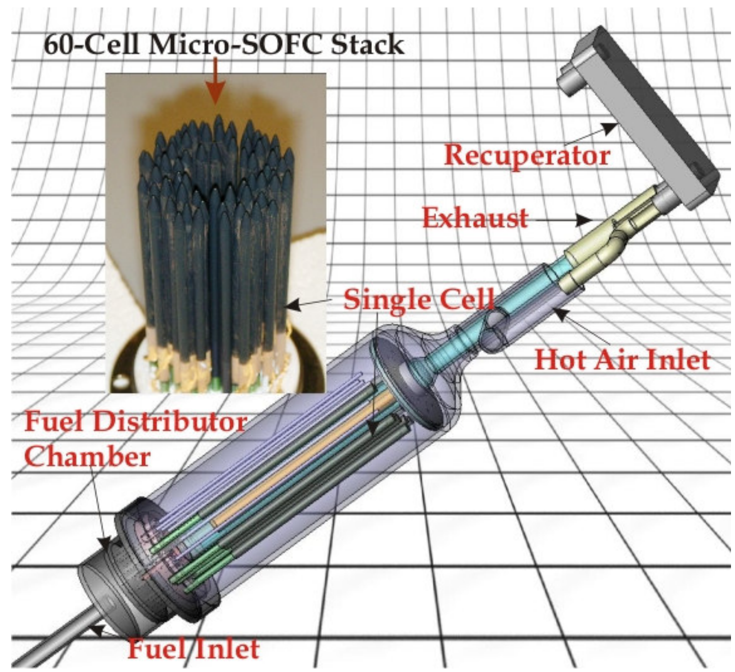
- **International Networks**
  - Government (NRC, NRCan), industry, and university participation
  - IPHE, IEA, HIA, AFCIA, BSIA
- **Academic Networks**
  - Funded by NSERC
  - Hydrogen, PEMFC, SOFC,
  - FCRC, OFCRIN, SOFC Canada, WCFCI. PEMFC Network, CANH2
- **SOFC Canada**
  - Four themes: Fuel processing, 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

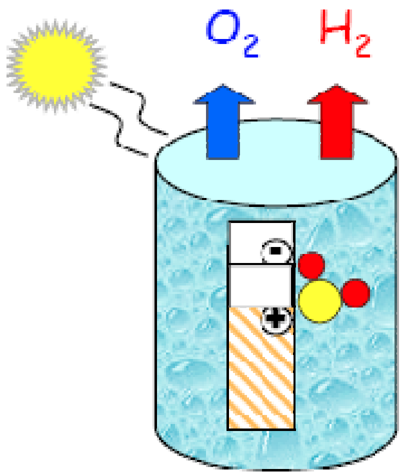


Porous electrolyte support Micro-tubular SOFC)



Hydrogen Production Materials Issues

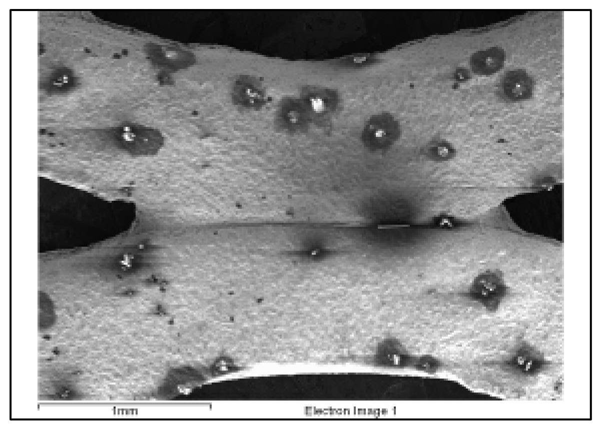
- **Splitting H_20**



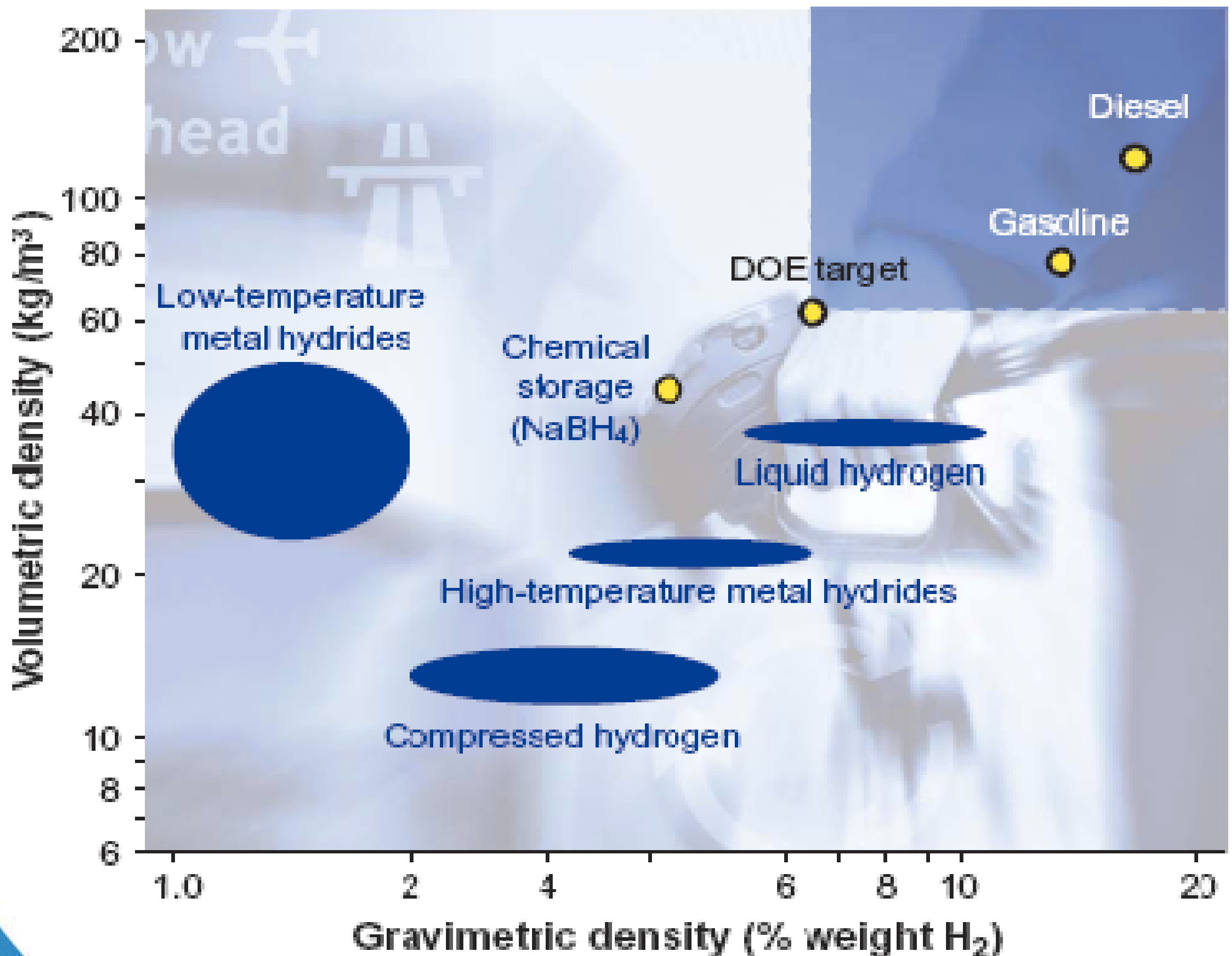
Solar electrolysis
Nano structured high surface
Band gap
Dye sensitized

•Electrolysis

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



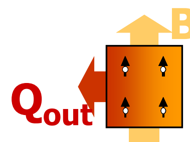
Hydrogen Storage Today: Gas and Liquid



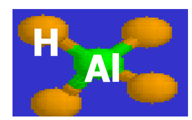
Hydrogen Storage Materials Issues

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

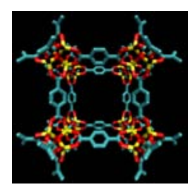
- **Magnetic Refridgerization**

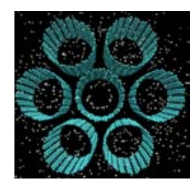


- **Complex Hydrides & metal Hydrides**



- **Nanostructured Materials**

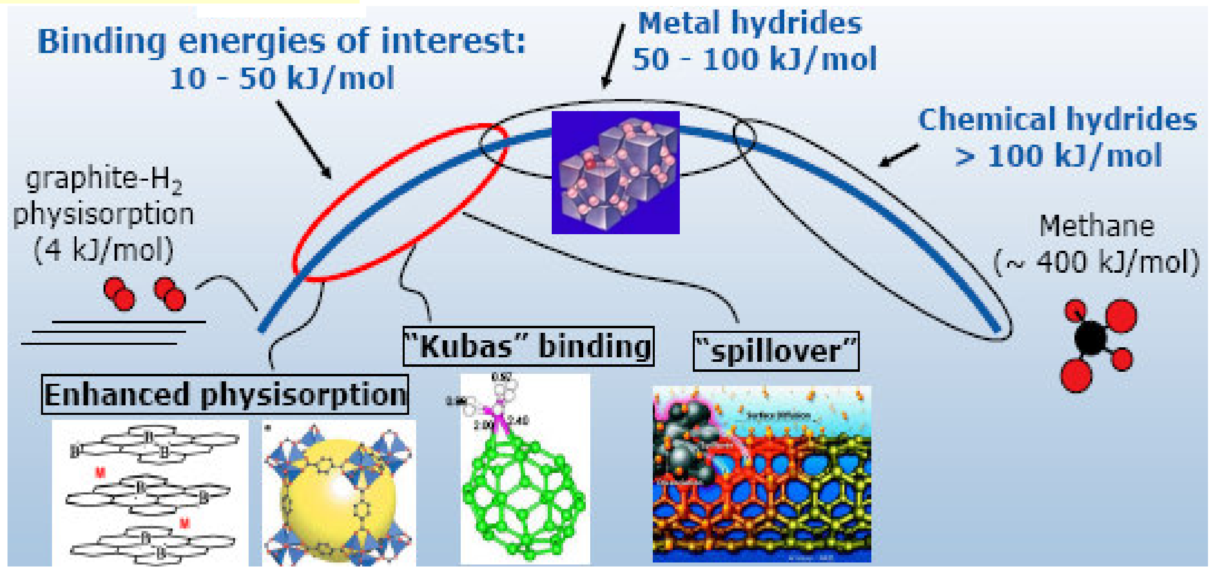




Continuum of Hydrogen Binding Energies

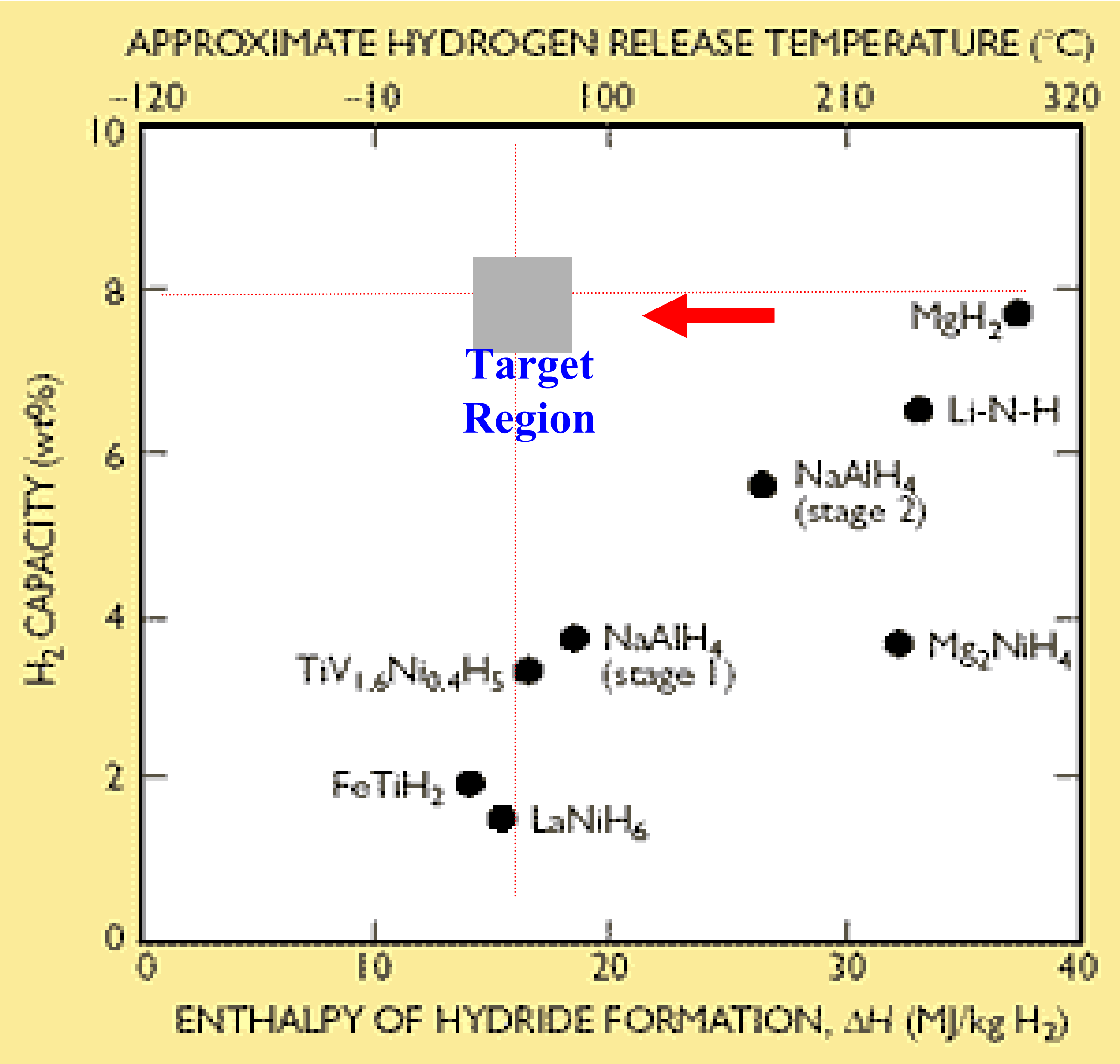
For reversible systems, equilibrium between gas and solid is given by:

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



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

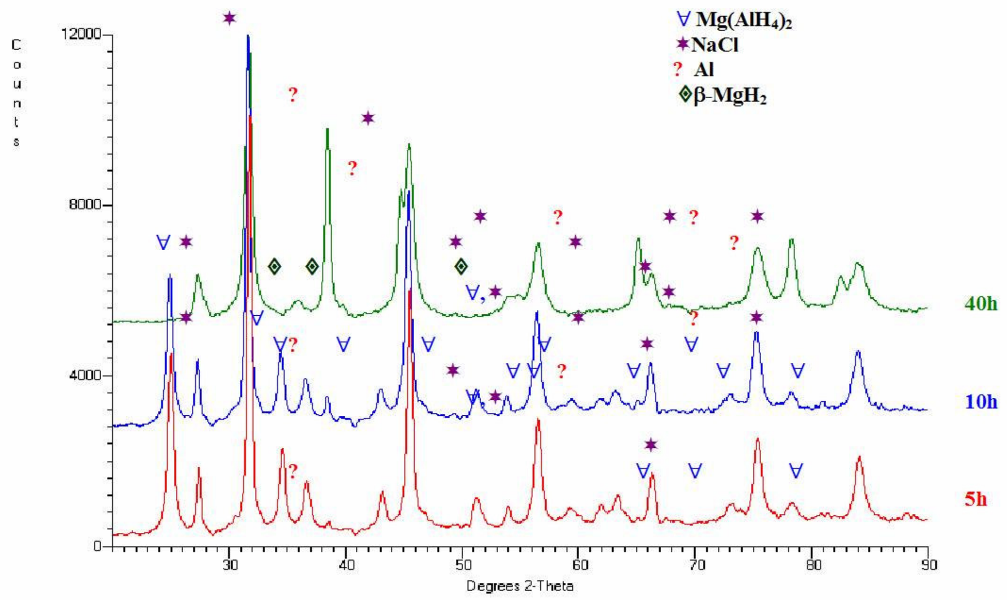
Issues with hydride storage



- 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

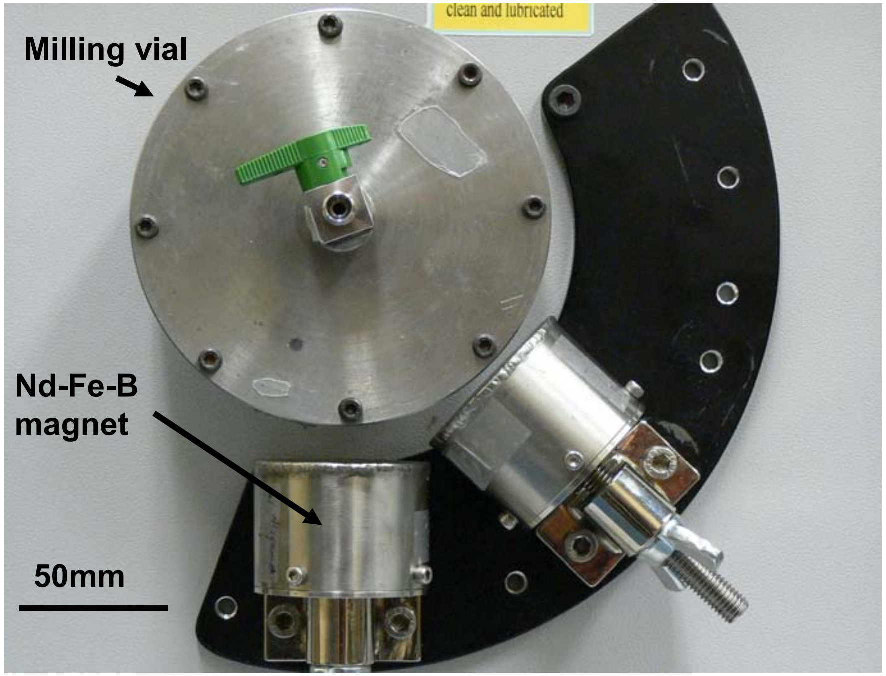
Stage 2:**decomposition** via redox disproportionation

Hydrogen Ball Milling

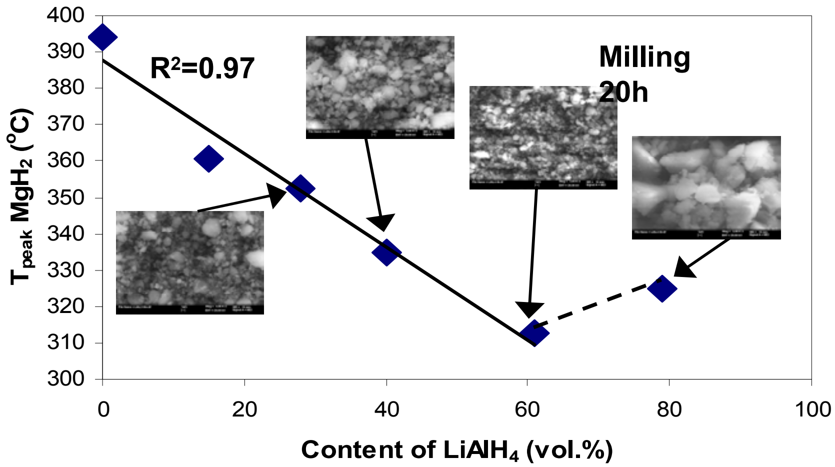
•Controlled mechanical modes of milling : Impact or Shear Mode

•Sequential supply of hydrogen gas

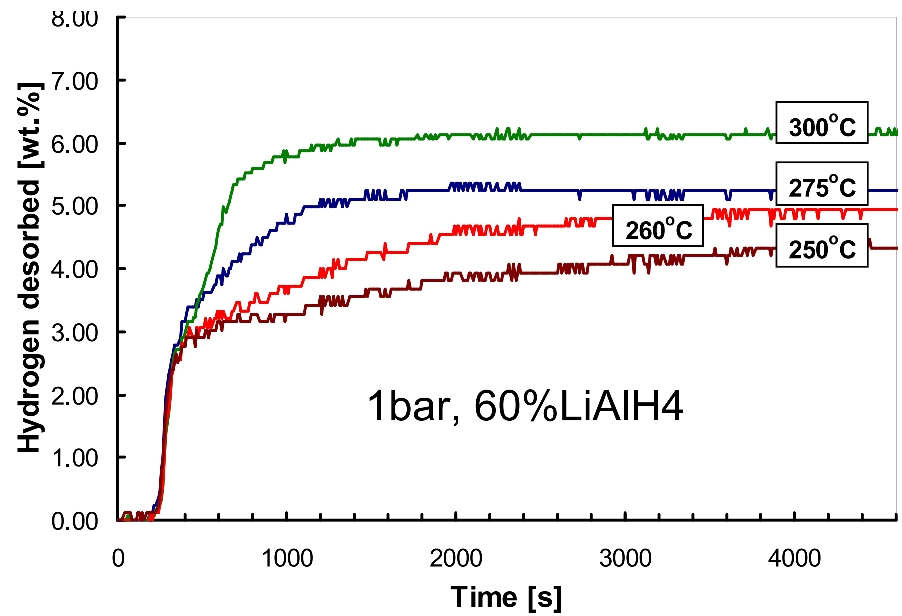
•Angular positions of Nd-Fe-B supermagnets under shear mode. The angular positions of external magnets can be changed for each of the controlled modes of milling.



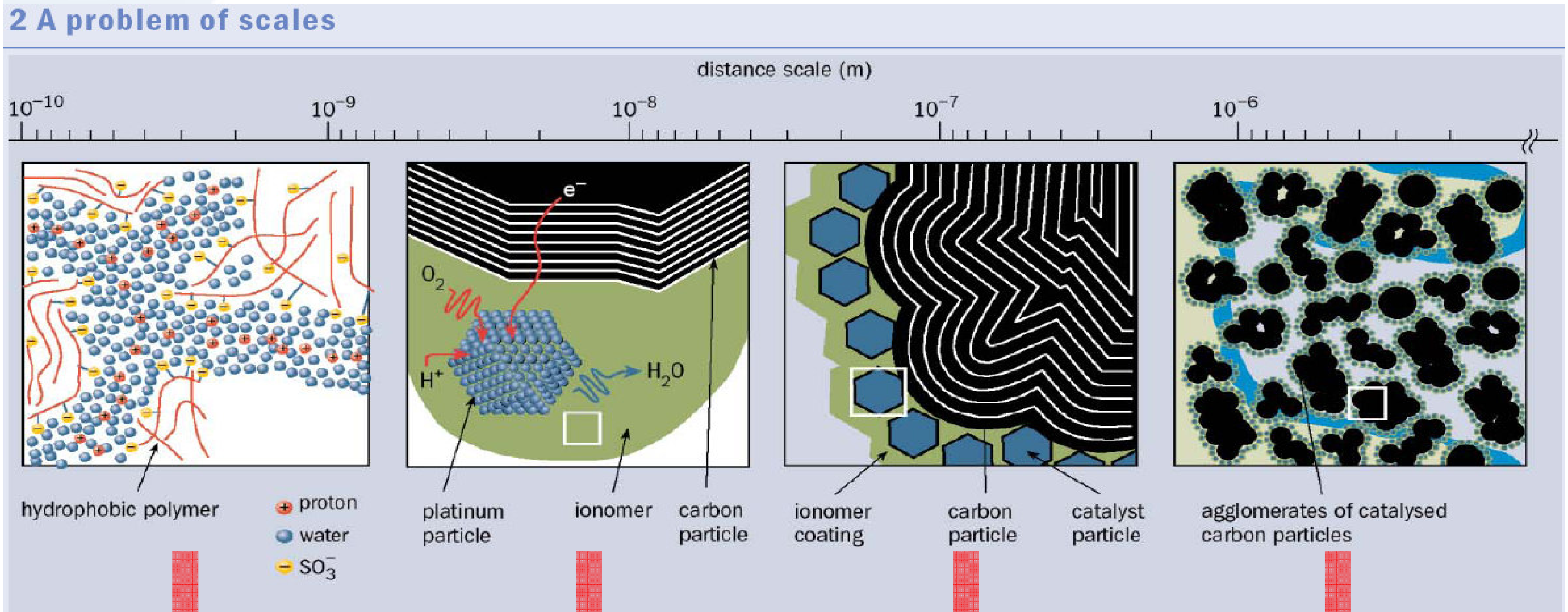
$MgH_2/LiAlH_4$ nanocomposite



MgH_2 destabilization by chemical hydride



Challenges for Materials and Operation PEMFC



Molecular scale, nanoscale

proton conductors: Higher Temperature

electrocatalysis: Pt dissolution

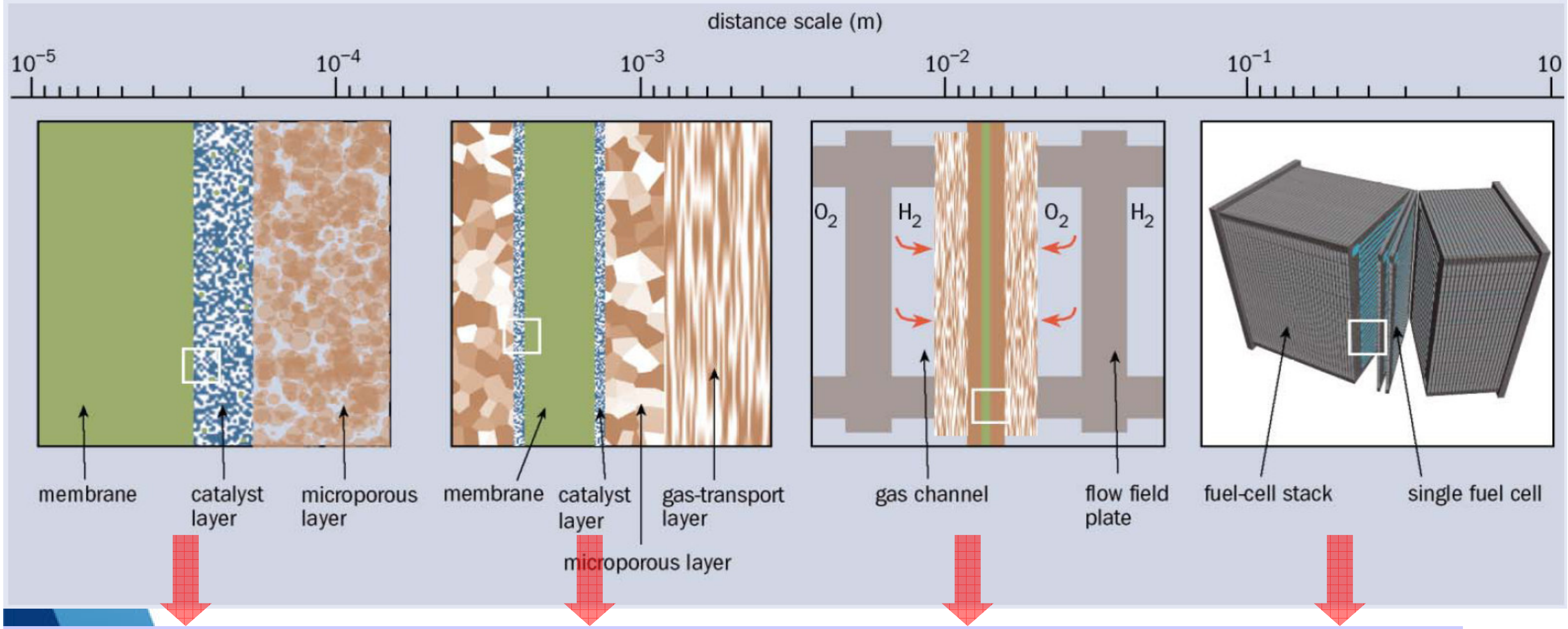
Mesoscale

Carbon support: stability

Macroscale

effective properties: Active surface area

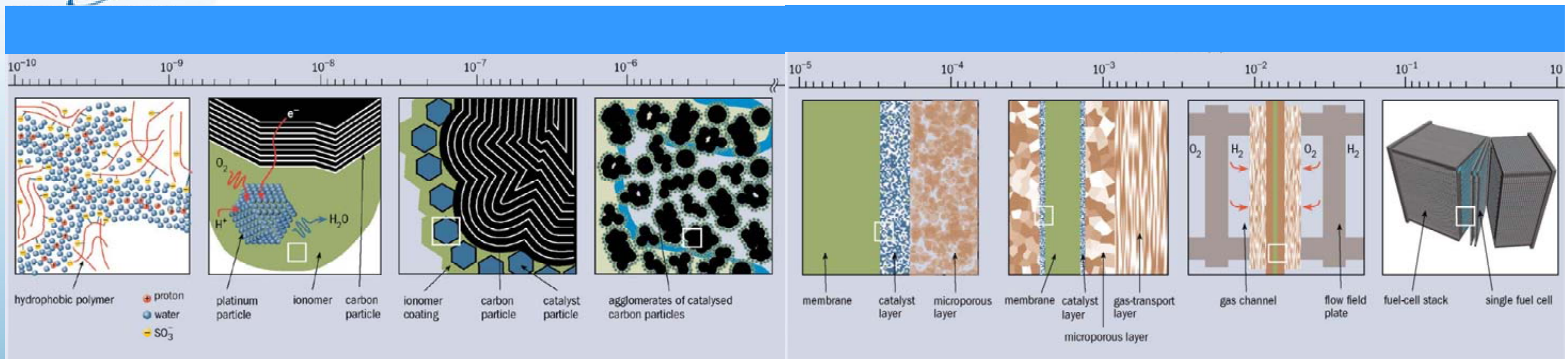
Challenges for Materials and Operation PEMFC



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



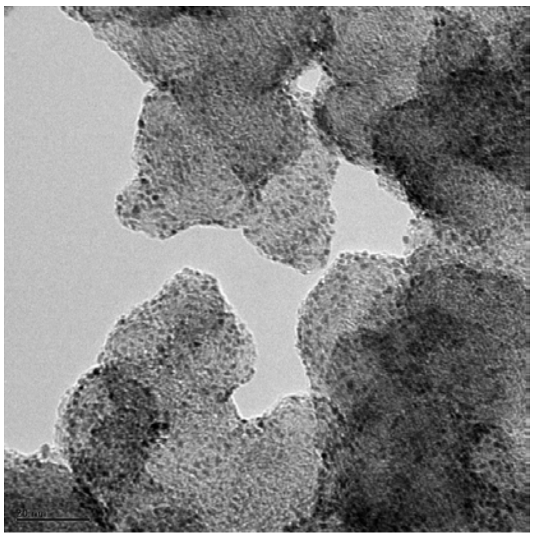
> 10 orders of magnitude,

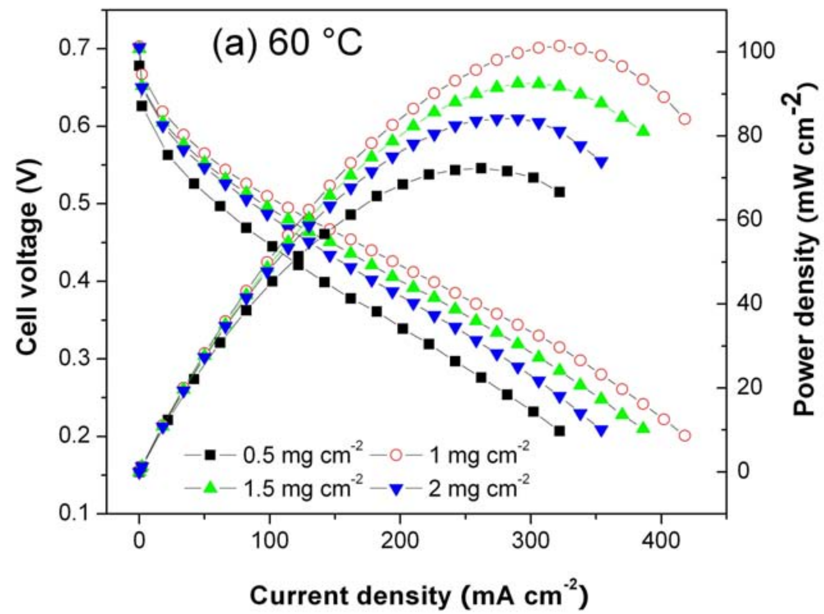
Multidisciplinary materials approach

- 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

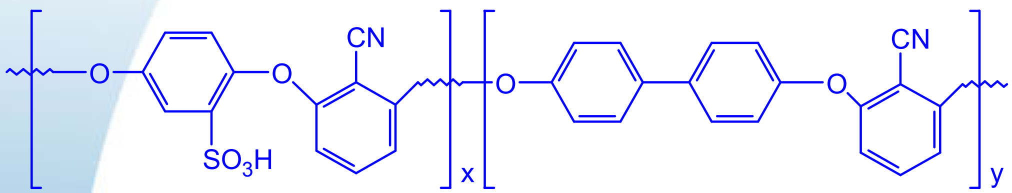
Modified polyol method using small stabilizers





•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

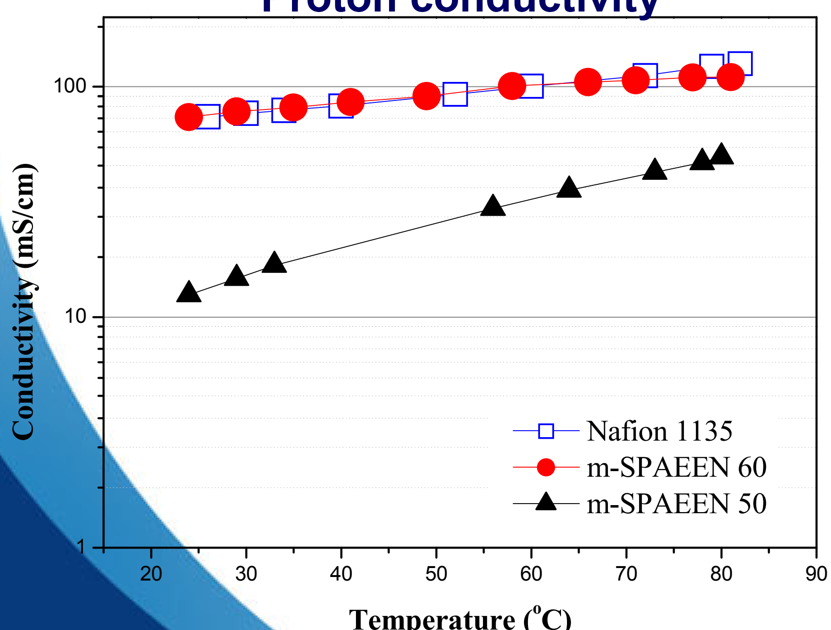
Polynitrile PEM Materials from Commercial Monomers

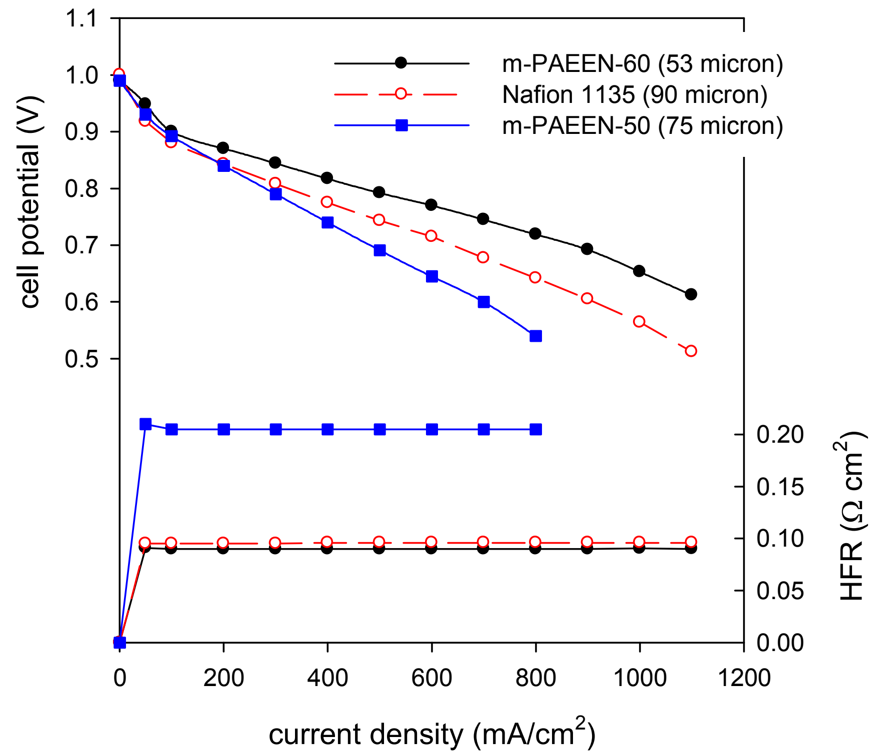


- Inexpensive
- High proton conductivity
- Low dimensional swelling
- Good catalyst adhesion
- Excellent cell performance
- Stable under MEA conditions

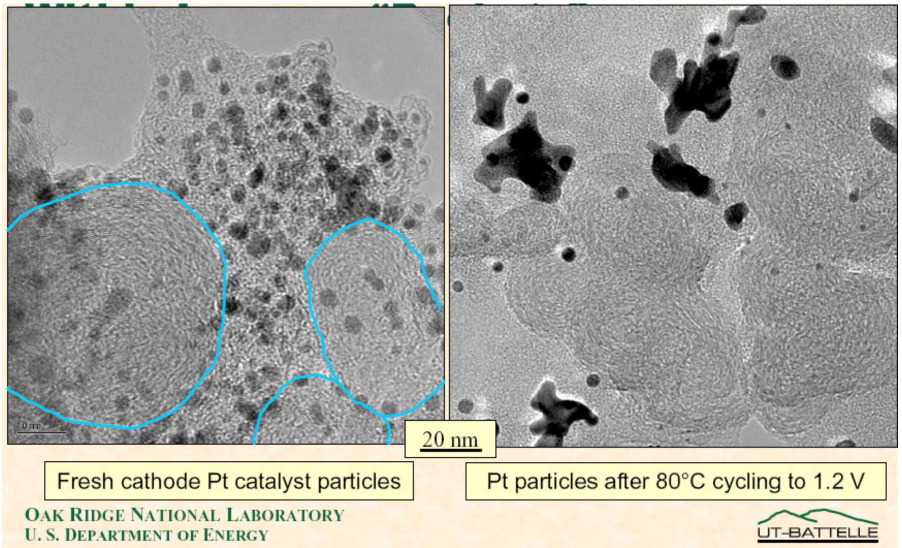
□ m-SPAEEN-60. Swelling 17% @ 80°C **● Nafion. Swelling 16-20% @ 80°C**

Proton conductivity





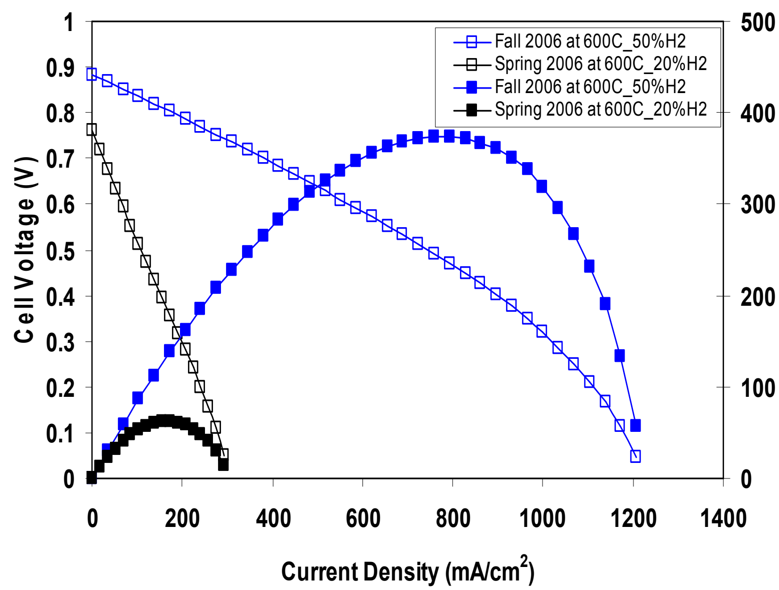
PEMFC Cathode Degradation



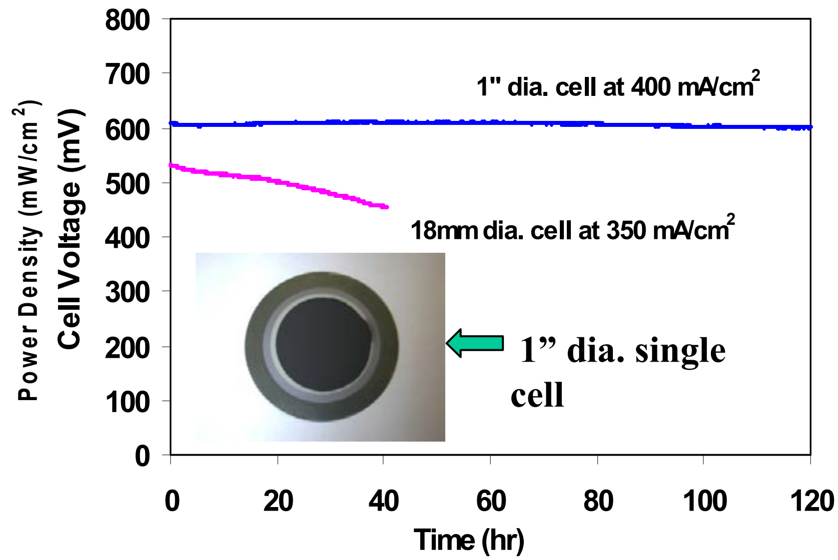
- High cathode voltage cycling causing Pt dissolution and recrystalization

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