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Renewable NH3 and Direct NH3 Fuel Cells: Canadian R&D for Clean Distributed Electricity Generation

Presented at
9th Annual NH3 Fuel Conference
San Antonio, TX

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CanmetENERGY is the R&D branch of Natural Resources Canada, with headquarters and labs in Ottawa ON, and labs in Varennes QC and Devon AB

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Introduction

Anhydrous ammonia (NH_3), the chemical building block for nitrogen fertilizers, is also a carbon-free fuel.

Considerable infrastructure is in place to transport and store NH_3 due to its extensive use in agriculture.

Direct NH_3 fuel cells can potentially produce electric power and high grade heat (CHP) efficiently and with zero emissions

Like hydrogen, NH_3 can be produced from non-fossil renewable electricity sources (hydro, wind). NH_3 production from renewable electricity, and NH_3 as a renewable fuel is gaining attention worldwide, particularly in the Corn Belt of US Midwest.

Topics:

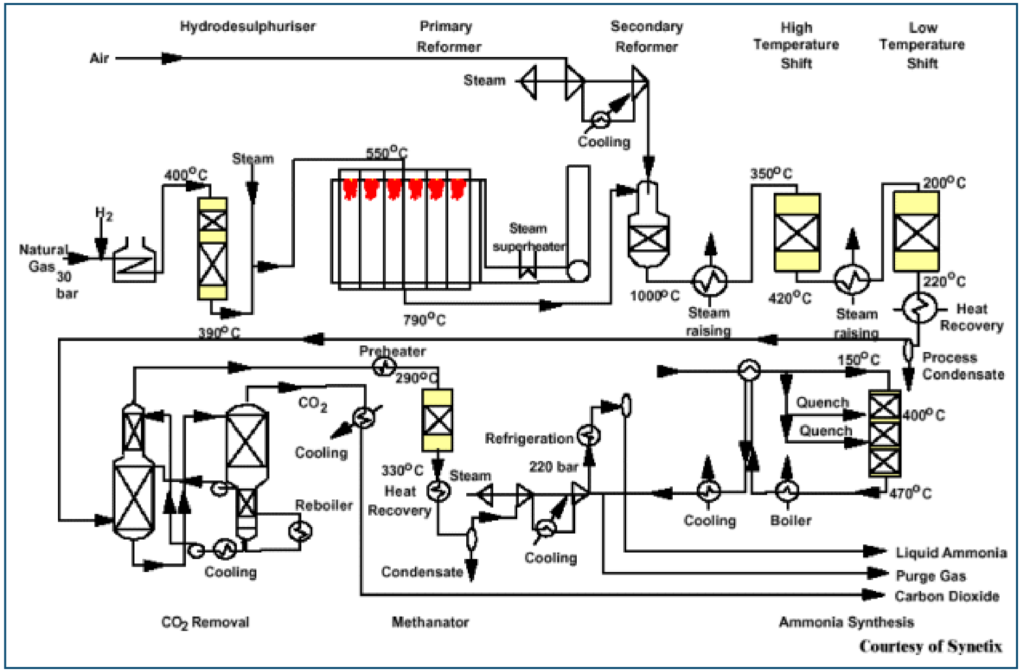
- Conventional NH3 production – energy requirements and GHG emissions
- Direct NH3 fuel cell development at CanmetENERGY
- Direct fuelling of conventional SOFC's with NH3
- NH3 as a carbon-free renewable fuel
- R&D needs and opportunities

Conventional (Fossil) NH3 Production

- ~200 million tonnes global capacity annually
- Production: 67% natural gas-based, 27% coal-based
- Use: >80% NH3 is used for fertilizer manufacture
- US imports >50% of its NH3
- Canada exports ~50% of its NG to US

- Also, NH3 Production from NG or coal produces pure CO2 byproduct which lowers cost of large scale CCS – and can be used for enhanced recovery of oil or coal-bed methane (NH3 from coal with CCS practiced commercially in Beulah N.Dakota since 2000)

NH3 Production from Natural Gas Reforming



Energy input: 30 million scf NG per tonne NH3 (30 GJ/tonne NH3)

CO2 Emissions: 1.8 tonnes CO2 per tonne NH3

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Overall Efficiency and CO_2 Emissions During Production and Distribution of Hydrogen Energy Carriers

(H. Anderson, World Hydrogen Energy Conference, Montreal, 2002)

Conclusions drawn from studies done by Norsk Hydro:

- CO_2 capture and sequestration contributes only slightly to the losses in the full hydrogen value chain
- **Central hydrogen and ammonia production seem to be the most efficient way to produce CO2-free energy carriers**
- **Ammonia infrastructure development is easier because truck transport is possible** – supply and demand will be in balance through time
- On site natural gas reforming and methanol steam reforming have highest CO_2 emissions

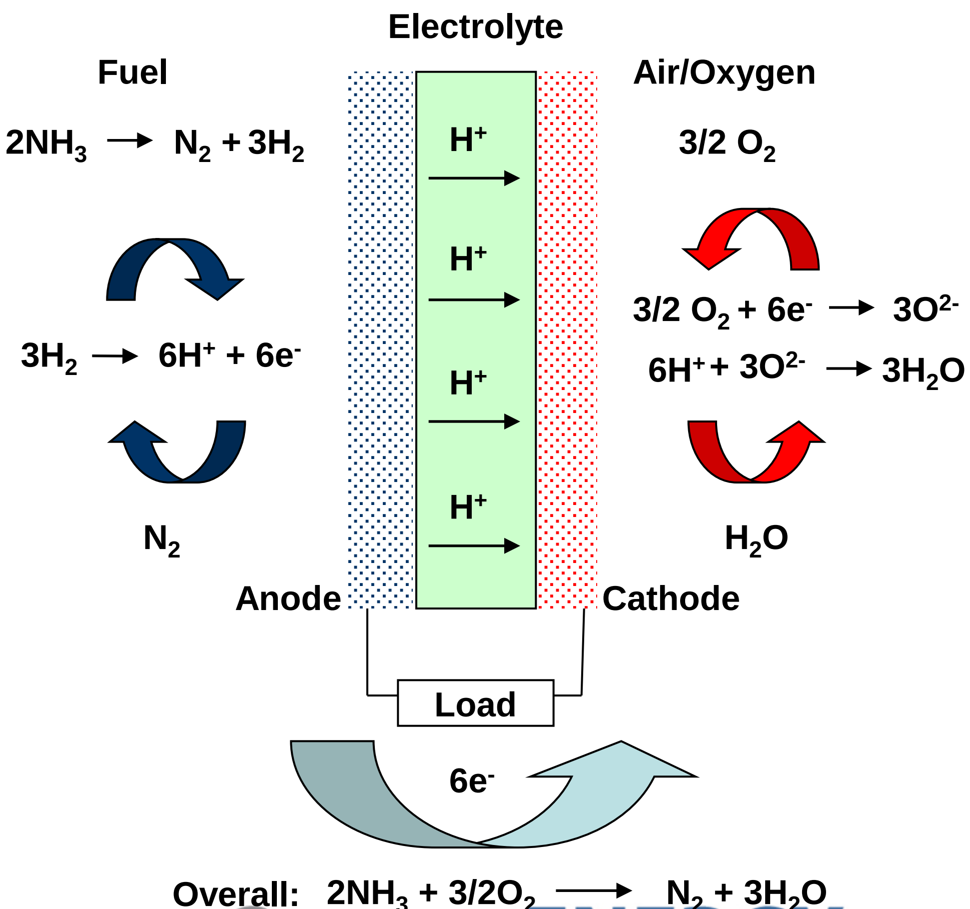
Direct NH3 Fuel Cells:

Development of Proton-Conducting Ceramic FC Materials at CanmetENERGY

Direct NH3 Fuel Cells:

What is the concept?

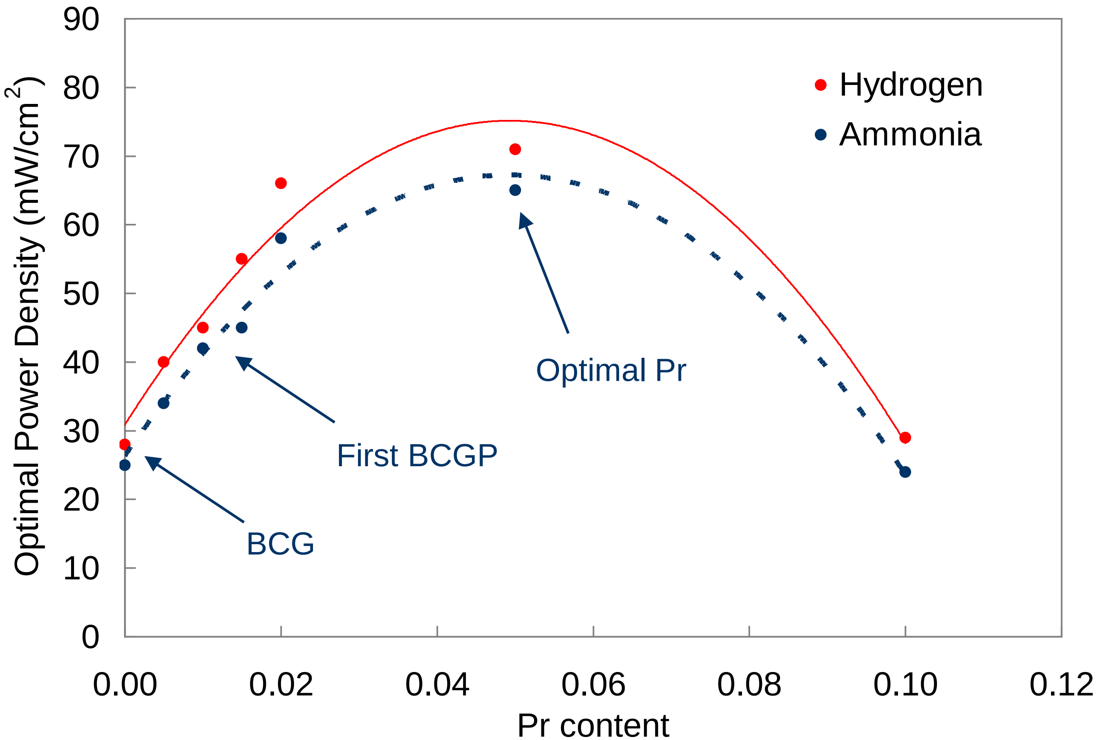
- Ammonia is catalytically decomposed to N_2 + H_2 at anode
- high temperature, low pressure favors equilibrium limited decomposition
- Protons transport across a solid proton conducting electrolyte.
- Removal of hydrogen at the anode drives decomposition reaction to completion.
- H_2/air oxidation at the cathode provides chemical driving force for the fuel cell AND provides the heat of reaction for ammonia decomposition.
- Products of the fuel cell are nitrogen, water, electric power and heat.



Direct NH3 Fuel Cells:

Pt/BCGP/Pt Ammonia Single Cell Fuel Cell

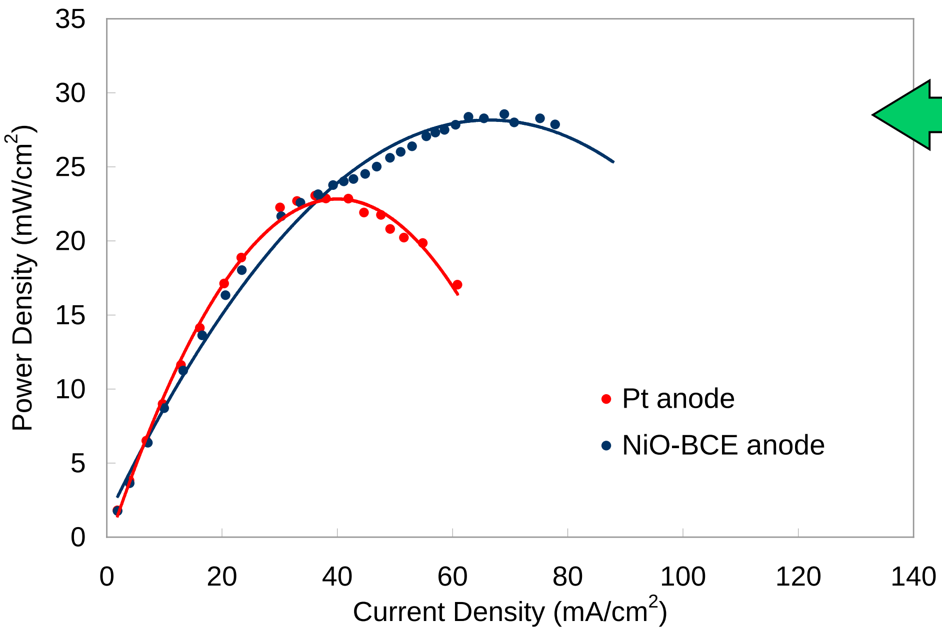
- Cell performance as a function of Pr concentration (700° C).
- Optimization at approximately Pr – 0.05 ($BaCe_{0.8}Gd_{0.15}Pr_{0.05}$).
- Related to increased material density and decrease of cell unit volume.



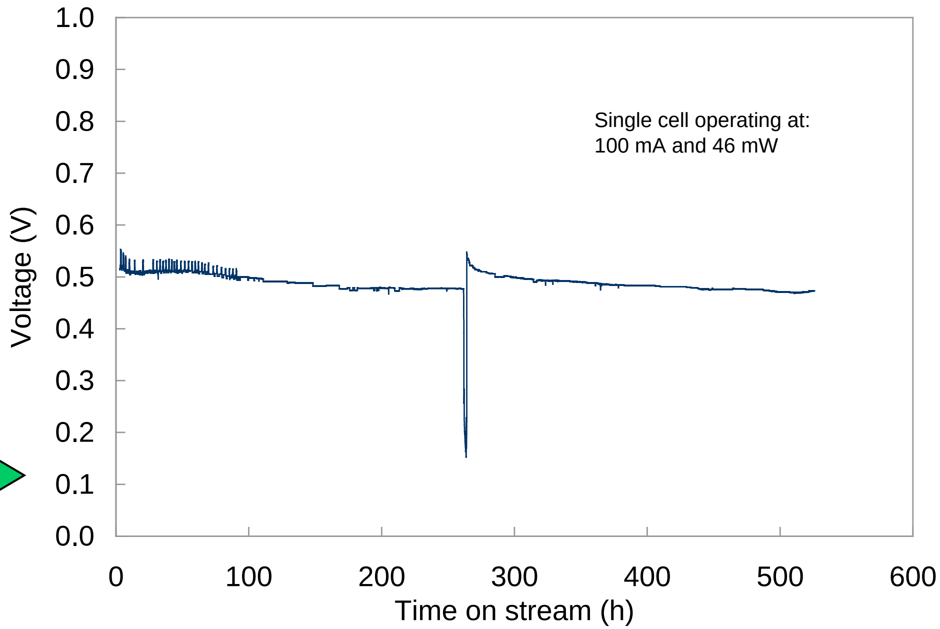
Fuel Cells, volume 7, issue 4 (2007) 323.

Direct NH3 Fuel Cells:

Mixed ionic and electronic conducting anode



NiO-BCE anode outperformed Pt anode in a BCGP electrolyte supported fuel cell at 600° C in NH_3



Cell was stable for over 500 h on ammonia fuel with very little degradation in performance.

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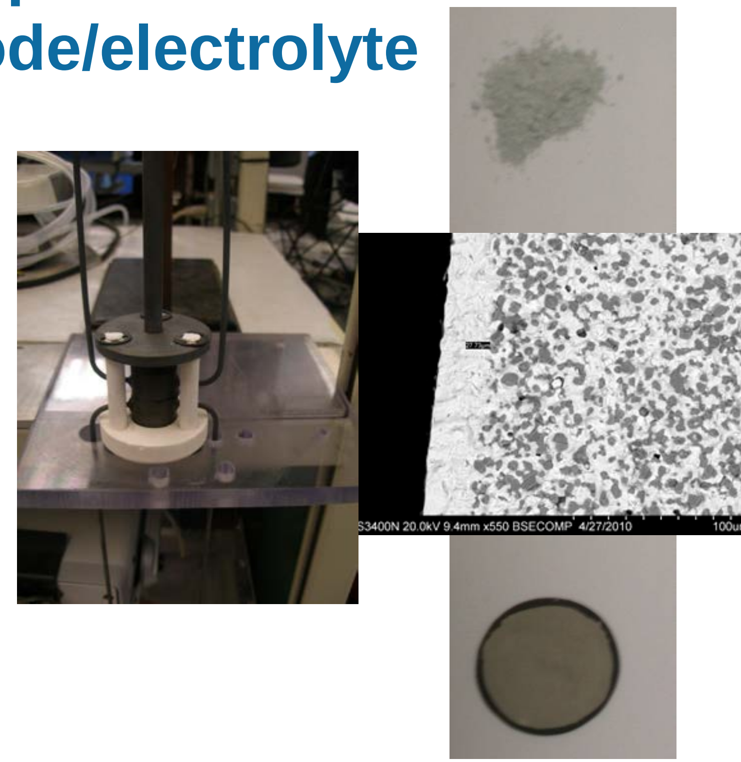
Direct NH3 Fuel Cells

In-house development of advanced proton conducting ceramic fuel cell electrode/electrolyte materials:

- Proton conducting ceramics allow lower operating temperatures in H2 and NH3
- They are thermodynamically more efficient than oxygen ion conducting ceramics
- X-section of Samarium doped barium cerate (BCS) under scanning electron microscope shows a uniform and dense ~25 micron thickness electrolyte layer, supported by a porous 1 mm thickness anode composed of NiO-BCS cermet
- This single fuel cell exhibits correct material properties needed for producing a fuel cell stack.



Direct NH3 Fuel Cells:

Testing NH3 on Conventional Precommercial SOFC Stacks at Acumentrics Canada

Acumentrics Canadian Division was established in 2007 at the Fuel Cell Research Centre in Kingston ON. CanmetENERGY partnered with them to do field testing of their stack using direct NH3 fuel.

RP-20 500W SOFC systems at a well head in Texas (2012)

Source: www.acumentrics.com

Acumentrics

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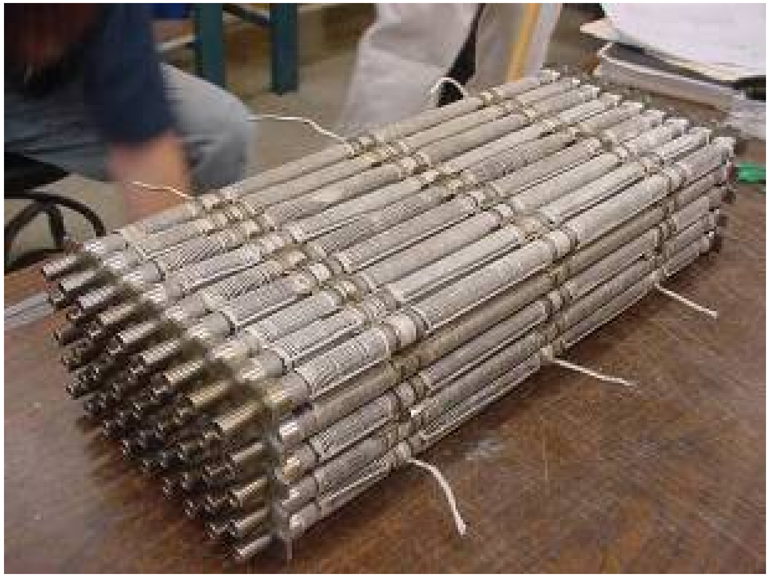
Direct NH3 Fuel Cells:

Acumentrics SOFC Direct NH3 Field Test



Objectives:

- Assess the technical feasibility of using ammonia as a direct fuel source in a SOFC micro CHP generator.
- Measure the long term stability and performance of the SOFC to see if the stack materials are degraded by direct NH3 fuel.
- Measure level of emissions, especially NOx in the stack effluent gas
- Determine the modifications required to a natural gas based system to allow it to operate on ammonia

Acumentrics SOFC stack:

- 9x5 array of extruded tubes
- NiO/YSZ anode support
- YSZ electrolyte
- shell (air) side cathode
- nominal 1 kW output

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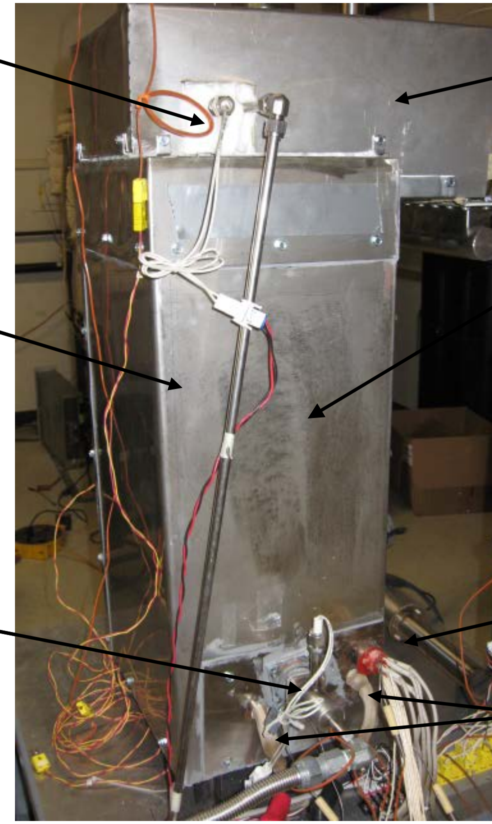
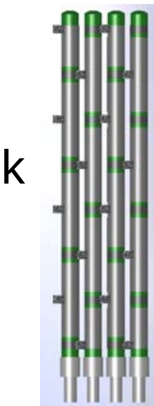
Direct NH3 Fuel Cells:
Acumentrics Custom SOFC Test Stand

Test Stand

Fuel Cell Module





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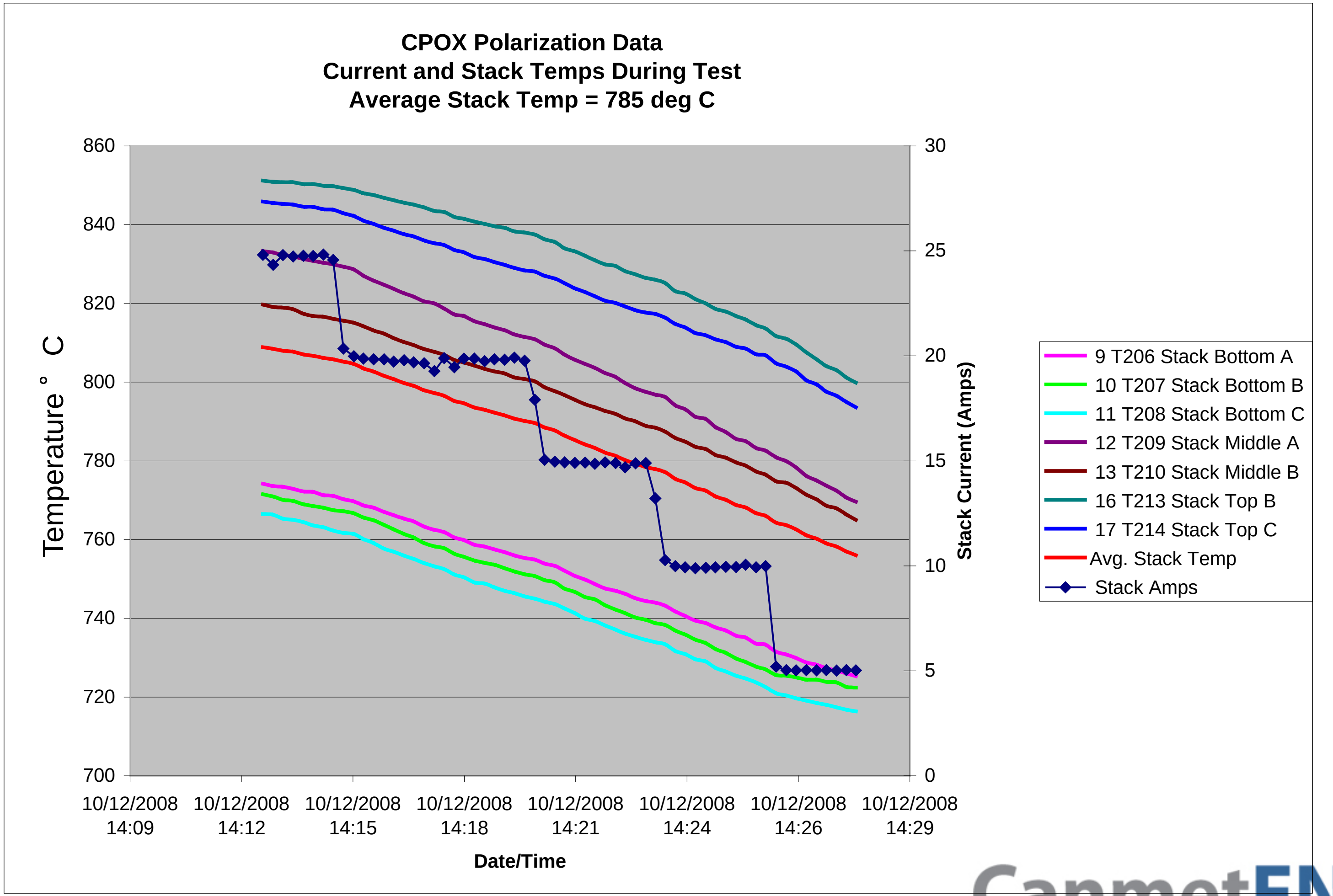
Direct NH3 Fuel Cells:
Acumentrics SOFC Stack Under Test



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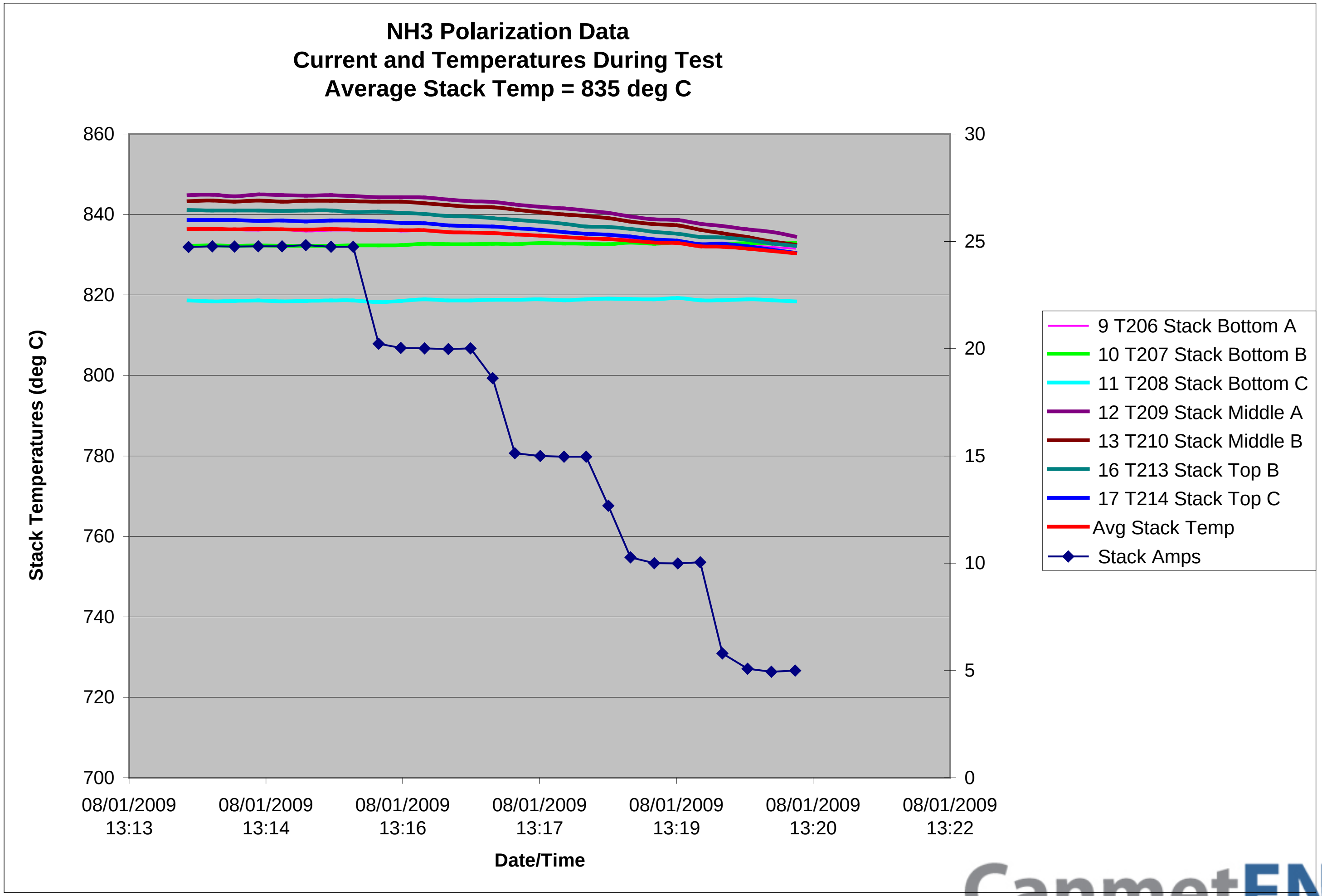
Temperature profile for CPOX Polarization Curve

Direct NH3 Fuel Cells:
Acumentrics SOFC Stack Under Test



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Temperature profile for NH3 Polarization Curve

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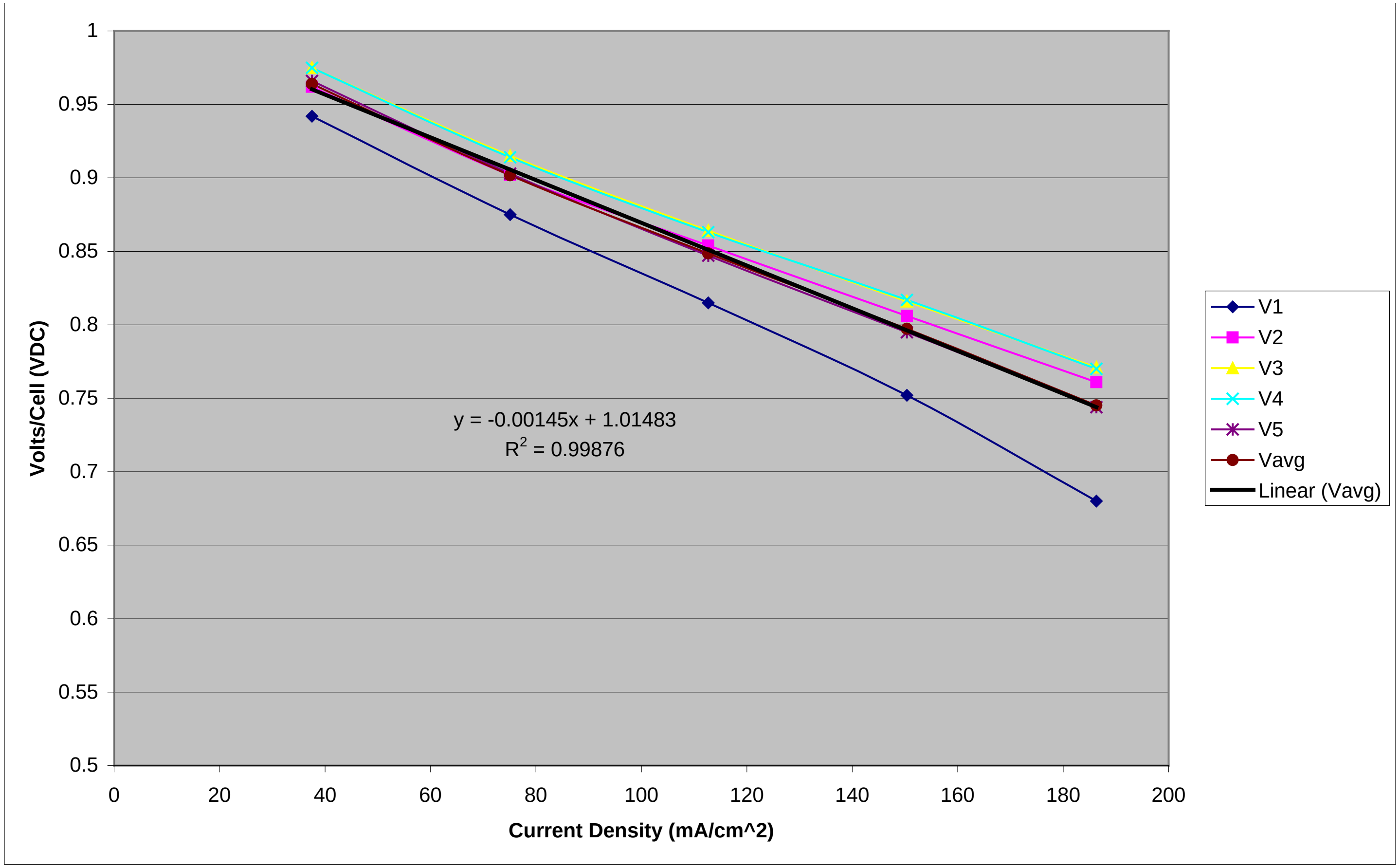
Acumentrics SOFC Stack Under Test



NH3 Polarization Curve

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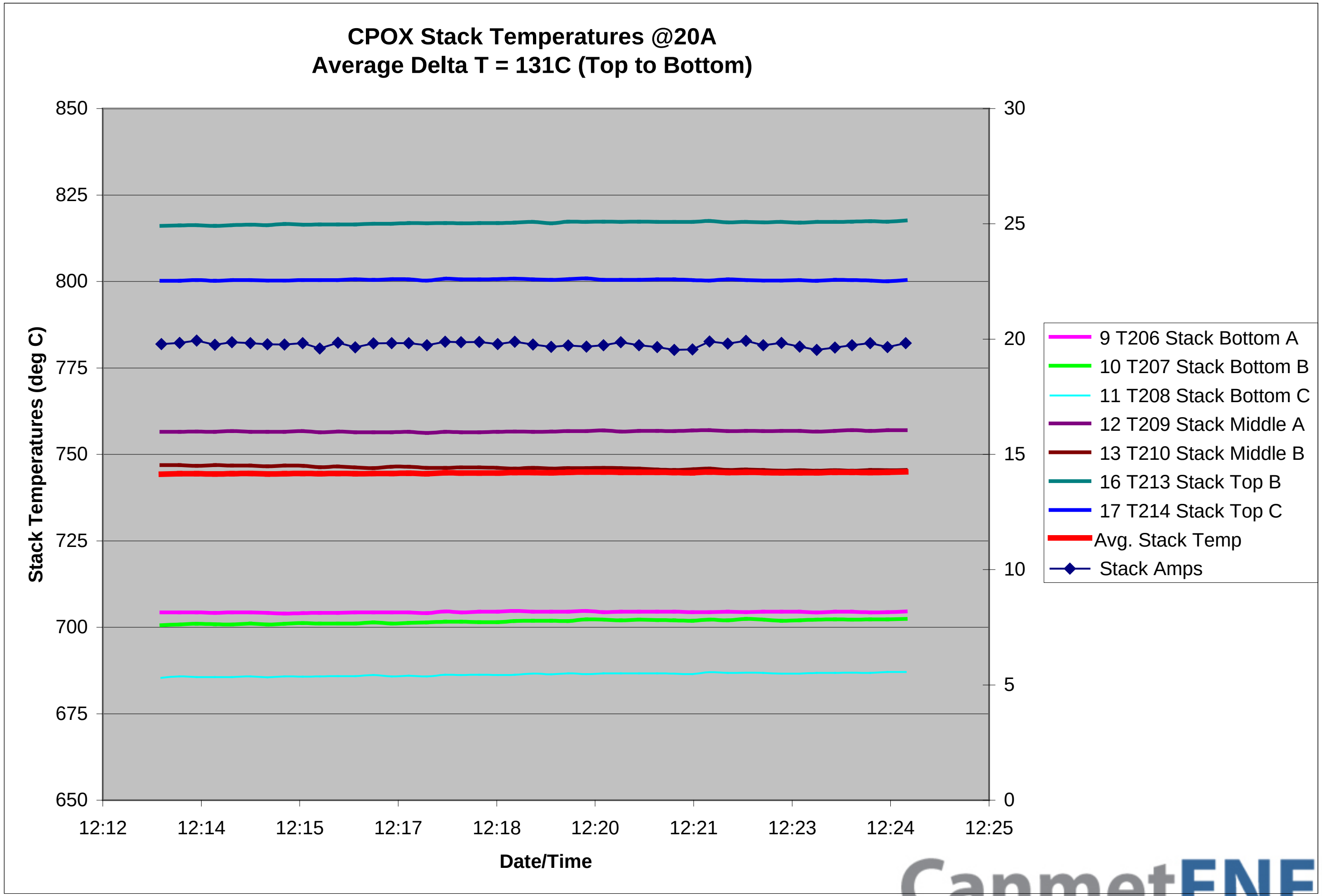
Acumentrics SOFC Stack Under Test



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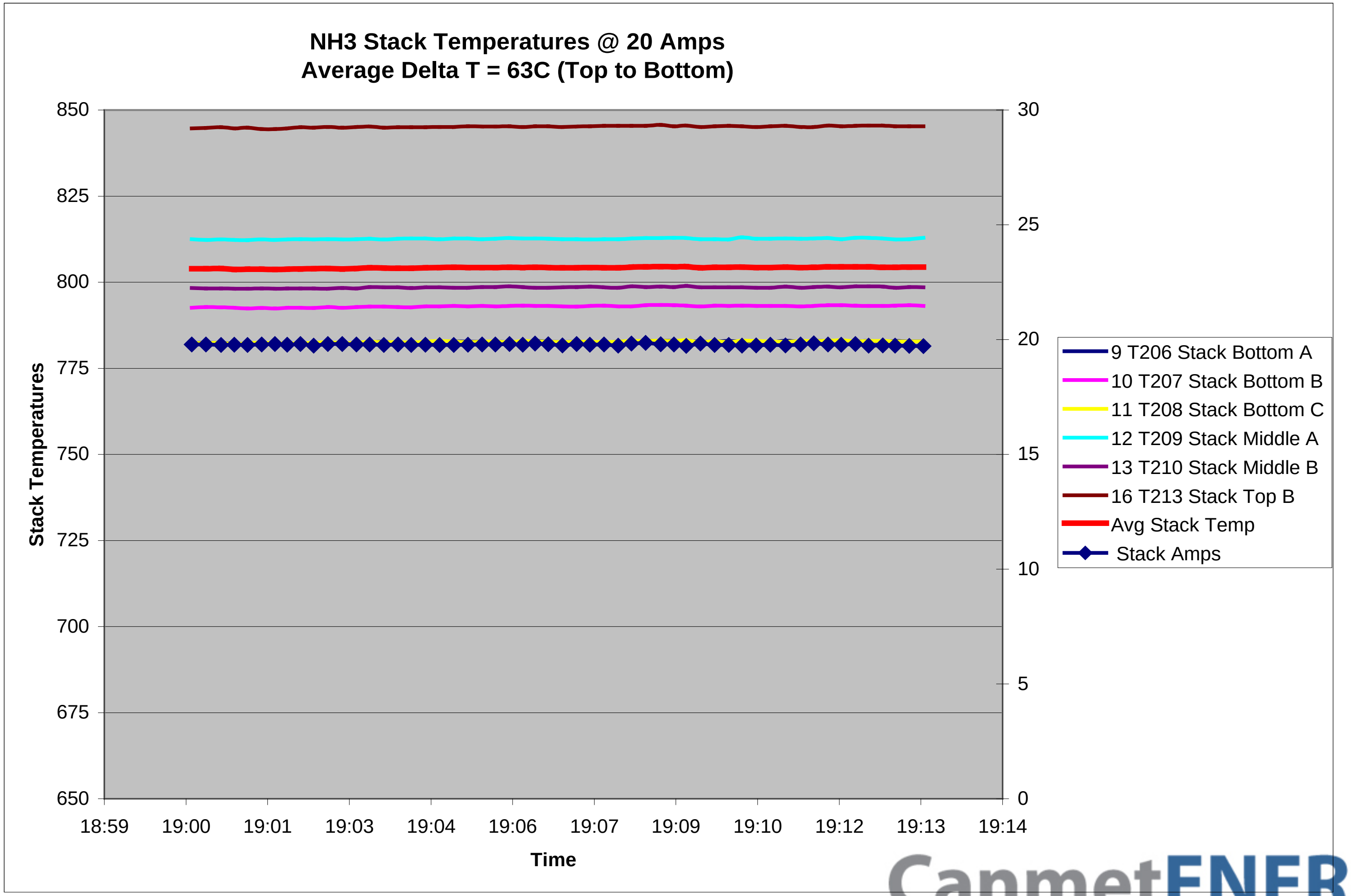
CPOX (Natural Gas) Operation @20A

Direct NH3 Fuel Cells:
Acumentrics SOFC Stack Under Test



NH3 Operation @20A

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Direct NH3 Fuel Cells:
Acumentrics NH3 SOFC Field Test

Knowledge Gained:

- Long term operation (~1400h) showed no adverse effects or drop off in stack performance for conventional SOFC.
- No residual NH_3, or NOx was detected in the stack effluent gas, or effectively zero emissions operating on ammonia.
- NH3 performance surpasses natural gas due to lower stack temperature gradient
- There is potential to simplify the system design considerably by using NH3, lowering cost to build the system

Independently in 2010, Topsoe Fuel Cells (Denmark) presented similar findings using their near commercial SOFC's

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Production and Use of Renewable "Green" NH3

NextHydrogen Study

NEXTHydrogen is a Canadian clean technology company who is developing MW scale electrolyzers as well as “green” applications of this technology

NEXT HYDROGEN

Economical Clean Hydrogen, at Scale

Innovation in Water Electrolysis™

NextHydrogen

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Canadian Opportunity for "Green" NH3: NextHydrogen Study

- Renewable NH3 (by water electrloysis, air separation, Haber Bosch synthesis) from low cost hydroelectricity ($0.02/kWh -$0.35/kWh) can be competitive with fossil NH3 in the near future. Windfarms with low installed costs and good to very good wind availability may also compete.
- Renewable (green) NH3 addresses energy security – for both energy and food production by reducing the industry's dependency on Canada's NG, heavy oil and coal resources.
- Green NH3 is an emerging decentralized (off grid) energy resource. It has the potential to reduce the GHG emissions related to fossil NH3 production.
- Demonstration ready technologies for using green NH3 as a fuel are available today. They include NH3 in internal combustion engines, and solid oxide fuel cell combined heat and power systems. NH3 production technology based on electrolysis is also at demo stage of development.

Economics of Natural Gas and Coal Based NH3 Production

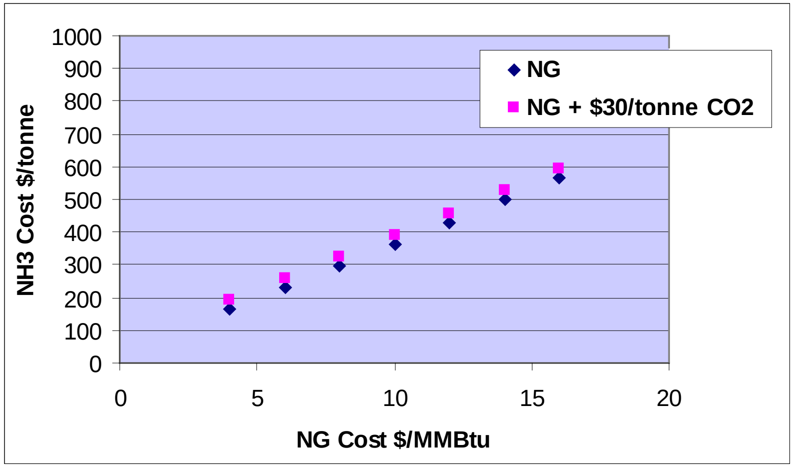

Fig.1

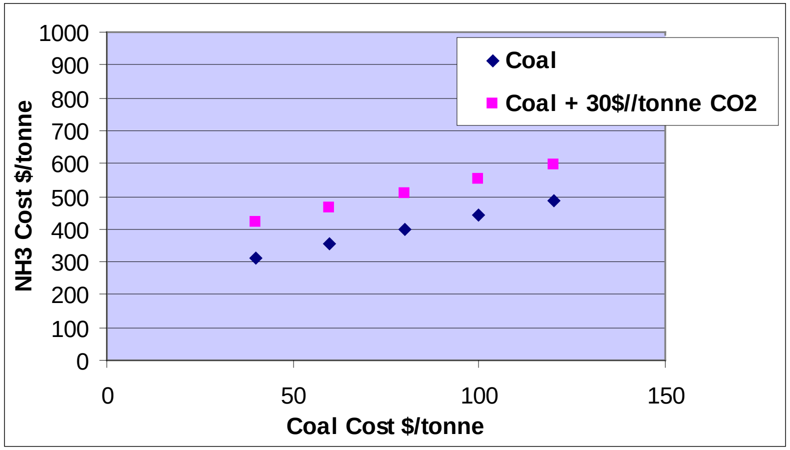

Fig.2

Fig.1 and Fig. 2 show that low-cost NG and/or coal based NH3 production remain economical for large scale production. Carbon Capture adds incrementally to production cost, more so for coal than NG.

Economics of "Green NH3"

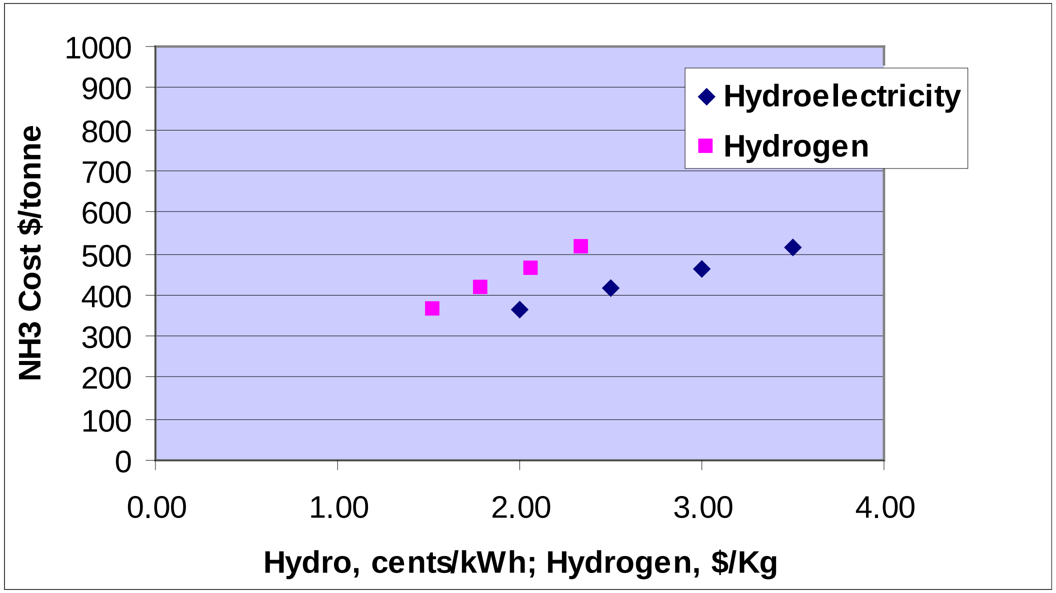

Fig.3

Fig. 3 shows that renewable NH3 from low cost hydroelectricity ($0.02-$0.35 /kWh) can be competitive with fossil NH3 in the near future. Hydrogen costing $1.50-$2.50 /Kg from wind energy will also be competitive.

Economics of “Green NH3”

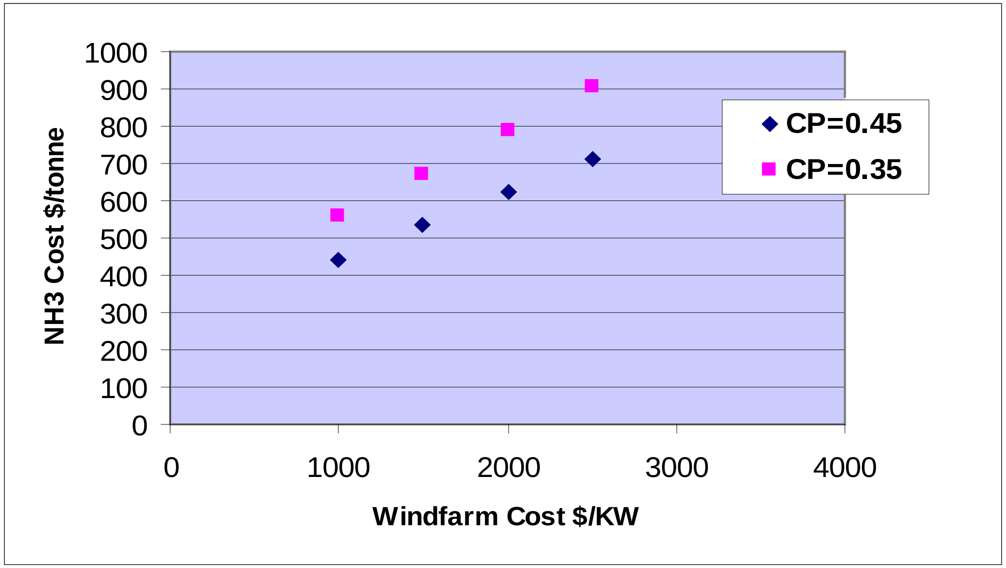

Fig.4

Fig. 4 shows the strong influence of wind farm installed cost and wind capacity factor (CP) on renewable NH3 cost. Wind farms require an installed cost approaching ~1000/kW, good wind (CP=0.35) or even very good wind (CP=0.45) to be competitive in today’s NH3 market.

Next Steps

- Pursue renewable NH3 production and technology demonstration tailored to match economic advantages of a given region.
- Pursue new applications for green NH3, e.g. farm vehicles, SOFC for CHP and refrigeration in regions where existing NH3 infrastructure can be leveraged.
- Pursue R&D on proton conducting ceramic electrolyte materials for efficient solid state electrochemical synthesis of ammonia.
- Nurture emerging Canadian expertise and technology development in related areas, and strengthen linkages nationally and internationally with entities having similar interests.
- R&D to advance biomass gasification for green NH3

Potential for Green NH3 Production From Biomass Gasification

ENERKEM (right) and **NEXTERRA** (below) are two Canadian companies who are developing syngas technologies based on biomass residues and MSW. These syngas processes could be utilized to produce liquid fuels, RNG, and green ammonia.

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“Green” NH_3 – An option for distributed clean energy and distributed NH_3 production in Canada ?

Thank You

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