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Direct Ammonia Fuel Cells for Distributed Power Generation and CHP

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CLEAN ENERGY TECHNOLOGIES

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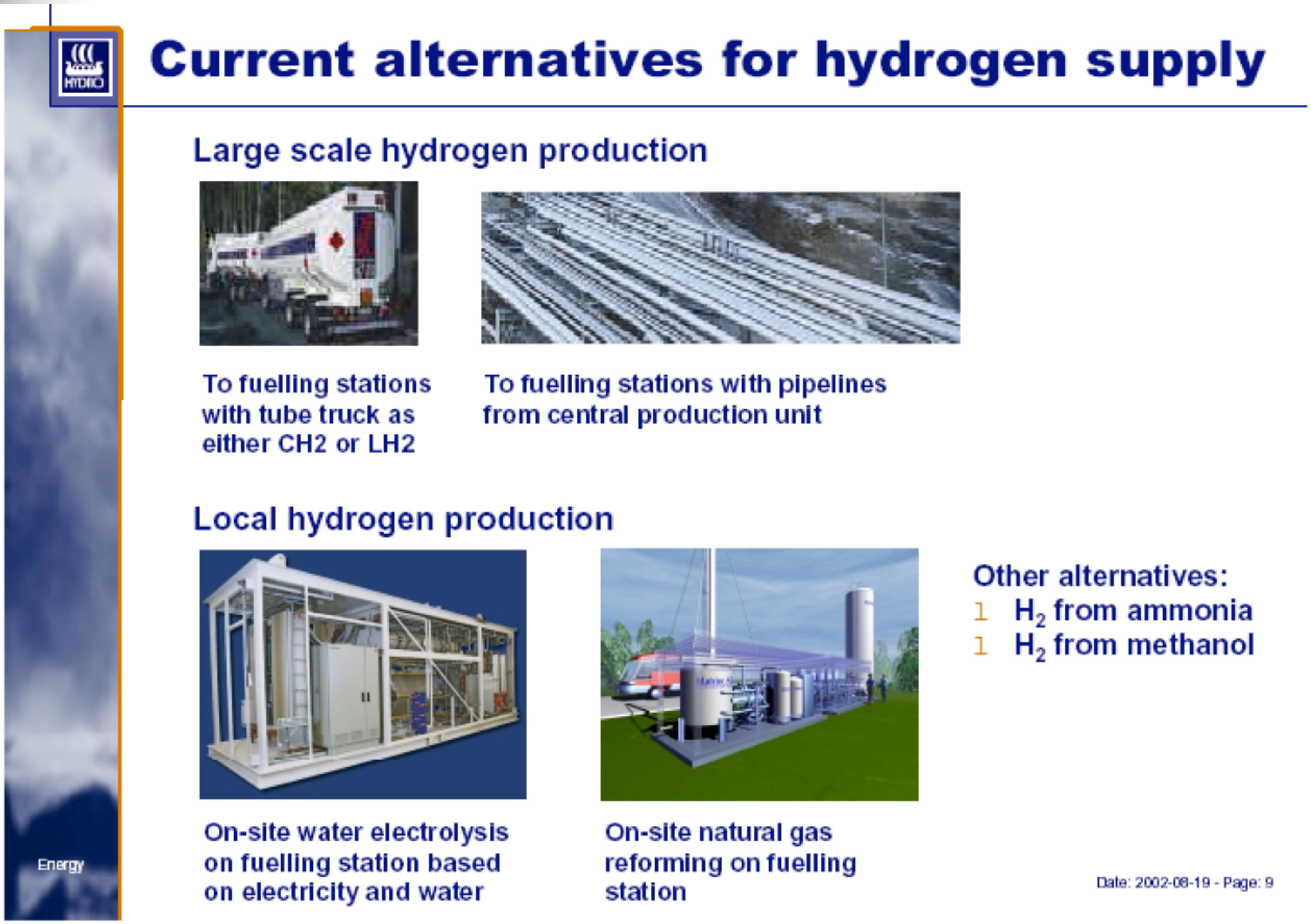
Canada

Rationale for Direct Ammonia Fuel Cells



Current alternatives for hydrogen supply

Large scale hydrogen production

To fuelling stations with tube truck as either CH2 or LH2

To fuelling stations with pipelines from central production unit

Local hydrogen production

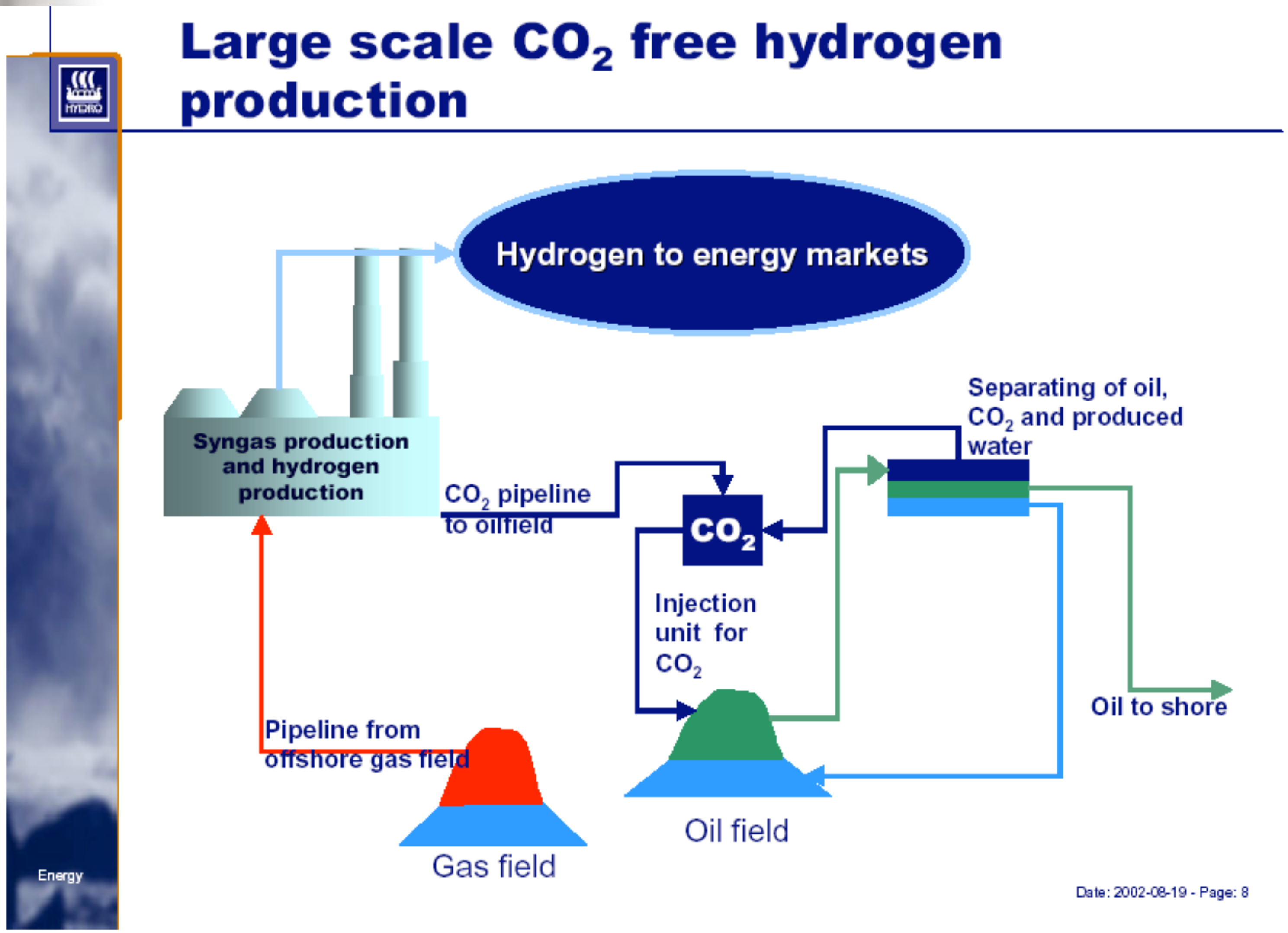
On-site water electrolysis on fuelling station based on electricity and water

On-site natural gas reforming on fuelling station

Other alternatives:
- H_2 from ammonia
- H_2 from methanol

Date: 2002-08-19 - Page: 9

Source: Norsk Hydro



Large scale CO_2 free hydrogen production

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Source: Norsk Hydro

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

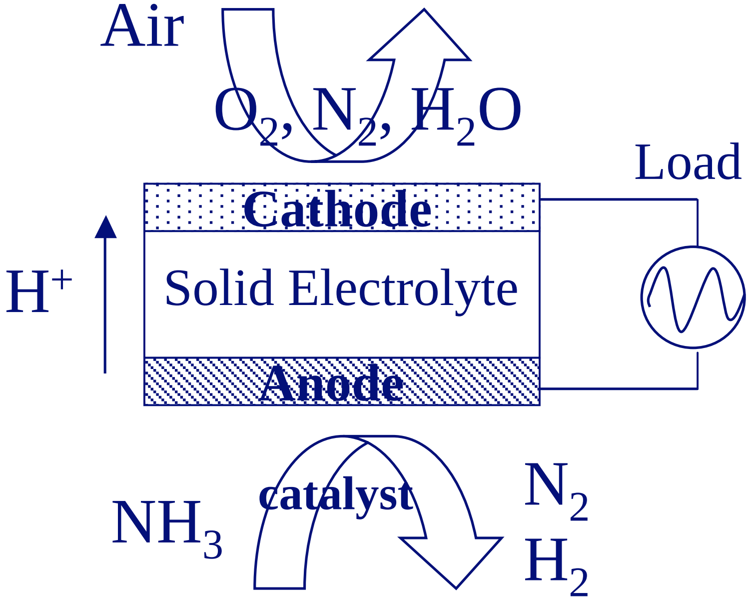
How does ammonia measure up as a fuel for fuel cells?

Fuel property	Ammonia	Methanol
Energy consumed to make, GJ/m.t.	27-28	28-31
Energy density, MJ/Kg (HHV)	22.5	22.7
Hydrogen content, % by weight	17.8	12.6
CO_2 emissions, Kg/Kg	0	1.38
Hazards	nonflammable toxic corrosive	flammable toxic noncorrosive
Transport/Storage	liquified gas 126 psia@20°C	liquid
Volume equiv. to 50L gasoline	137	101

Solid Electrolyte Ammonia Fuel Cell

What is the concept?

- Ammonia is catalytically decomposed to N_2 + H_2 at anode
- high temperature, low pressure favour 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.



Electrochemical Reactions in a Direct Ammonia Fuel Cell Using Proton Conducting Electrolyte

ANODE
(fuel side)

$$2\ NH_3 + \text{heat} \rightarrow 3\ H_2 + N_2$$

$$3\ H_2 \rightarrow 6\ H^+ + 6\ e$$

CATHODE
(air side)

$$3/2\ O_2 + 6\ e \rightarrow 3\ O^{2-}$$

$$6\ H^+ + 3\ O^{2-} \rightarrow 3\ H_2O + \text{heat}$$

OVERALL

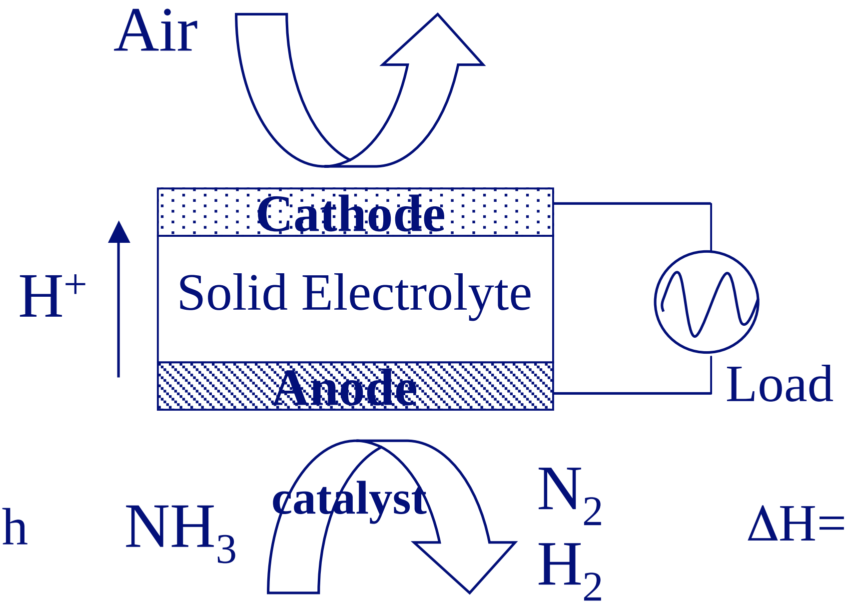
$$2\ NH_3 + 3/2\ O_2 \rightarrow N_2 + 3\ H_2O$$

What is the ammonia fuel cell energy balance?

"Ammonia Cracking":

$$2\,NH_3 \rightleftharpoons N_2 + 3\,H_2 \qquad \Delta H = 92.4\ \text{kJ/mol}$$

$$= 2.72\ \text{MJ/kg}\ NH_3$$



9.0 MJ/kg-h
2.5 kW thermal

10.8 MJ/kg-h
3.0 kWe
~55% eff.

-22.5MJ/kg-h

ΔH=2.7 MJ/kg-h

Relative Cost of Ammonia as Fuel for “Green” Electricity

The historical market price of anhydrous ammonia in the past decade has been about $150/ton:

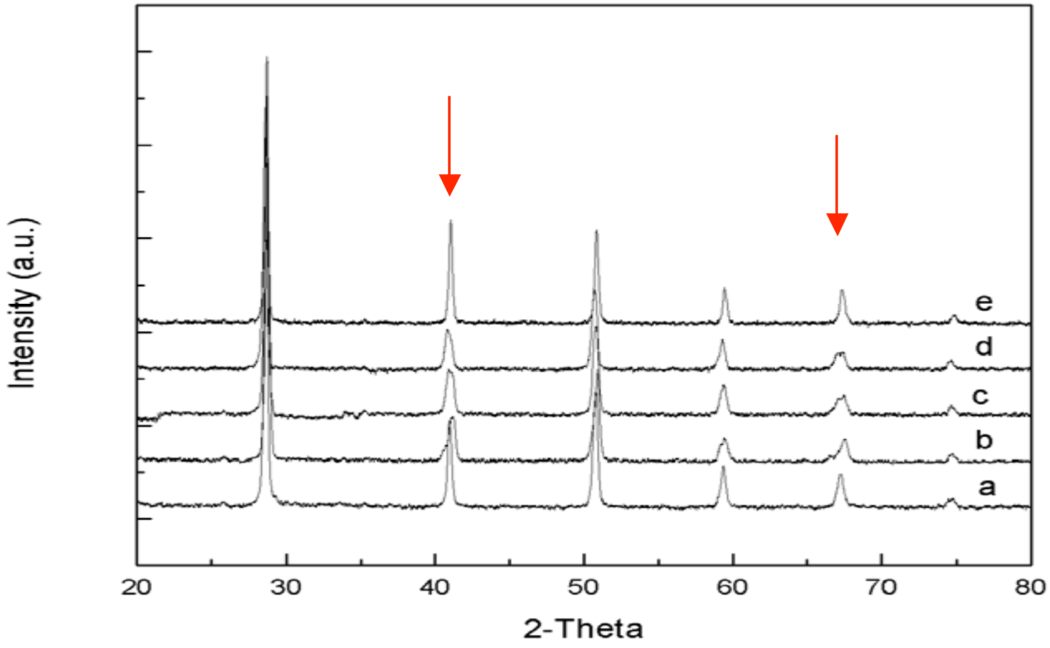
At $150/ton, the fuel cost of electricity is:	$0.05/KWH
At $300/ton…	$0.10/KWH

In Q4 2003, Ontario wholesale spot market for electricity (NGCC power at $7MMBtu/MWH) was around $0.05/KWH. Renewable “Green” power traded at around $0.09-$0.10/KWH.

A CO_2 emissions penalty of $150/ton for electricity generation is equivalent to about $0.05/KWH (NGCC).

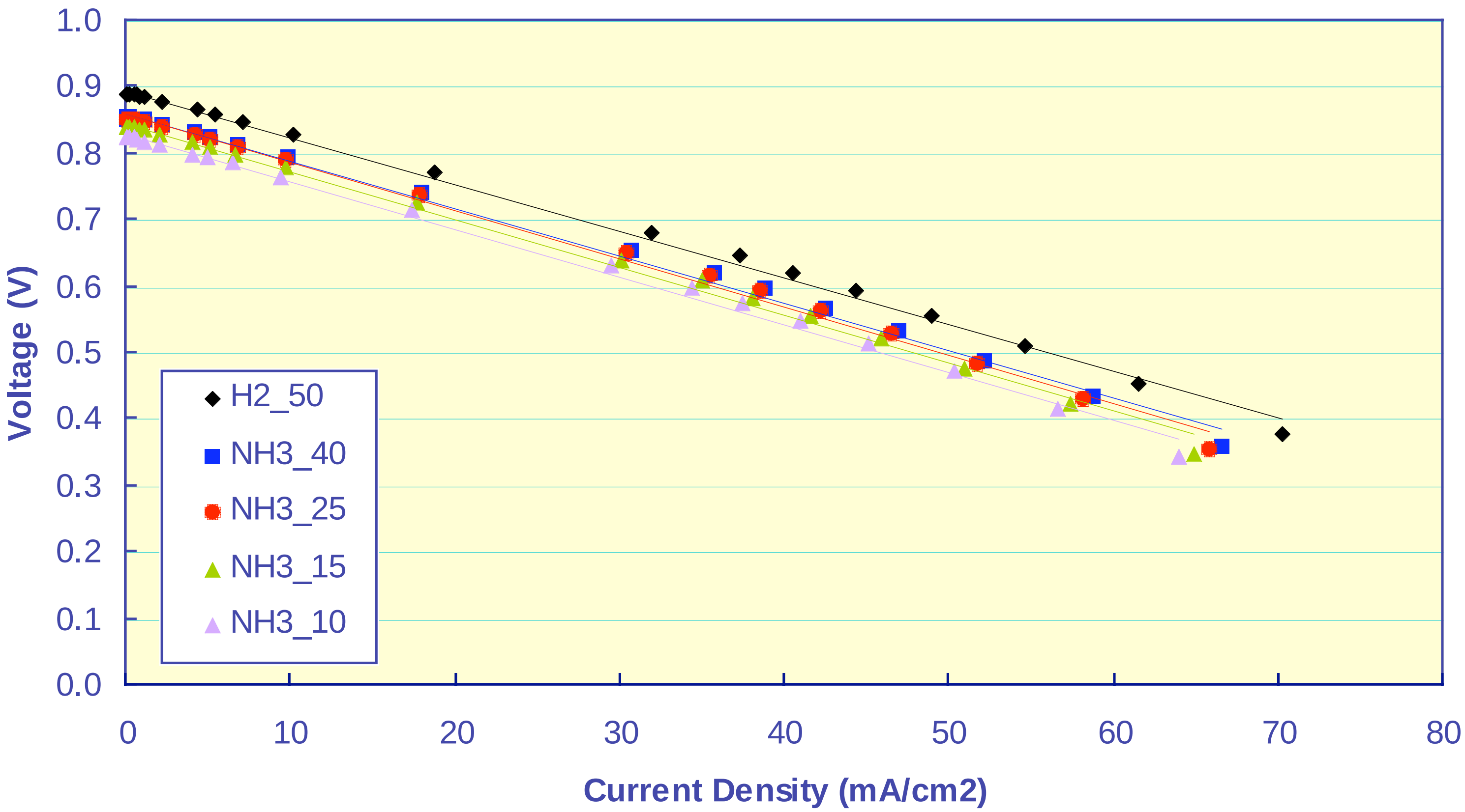
Fuel Cell Materials R&D Activities

$BaCe_{0.8}Gd_{0.2}O_{3-*}$ Electrolyte



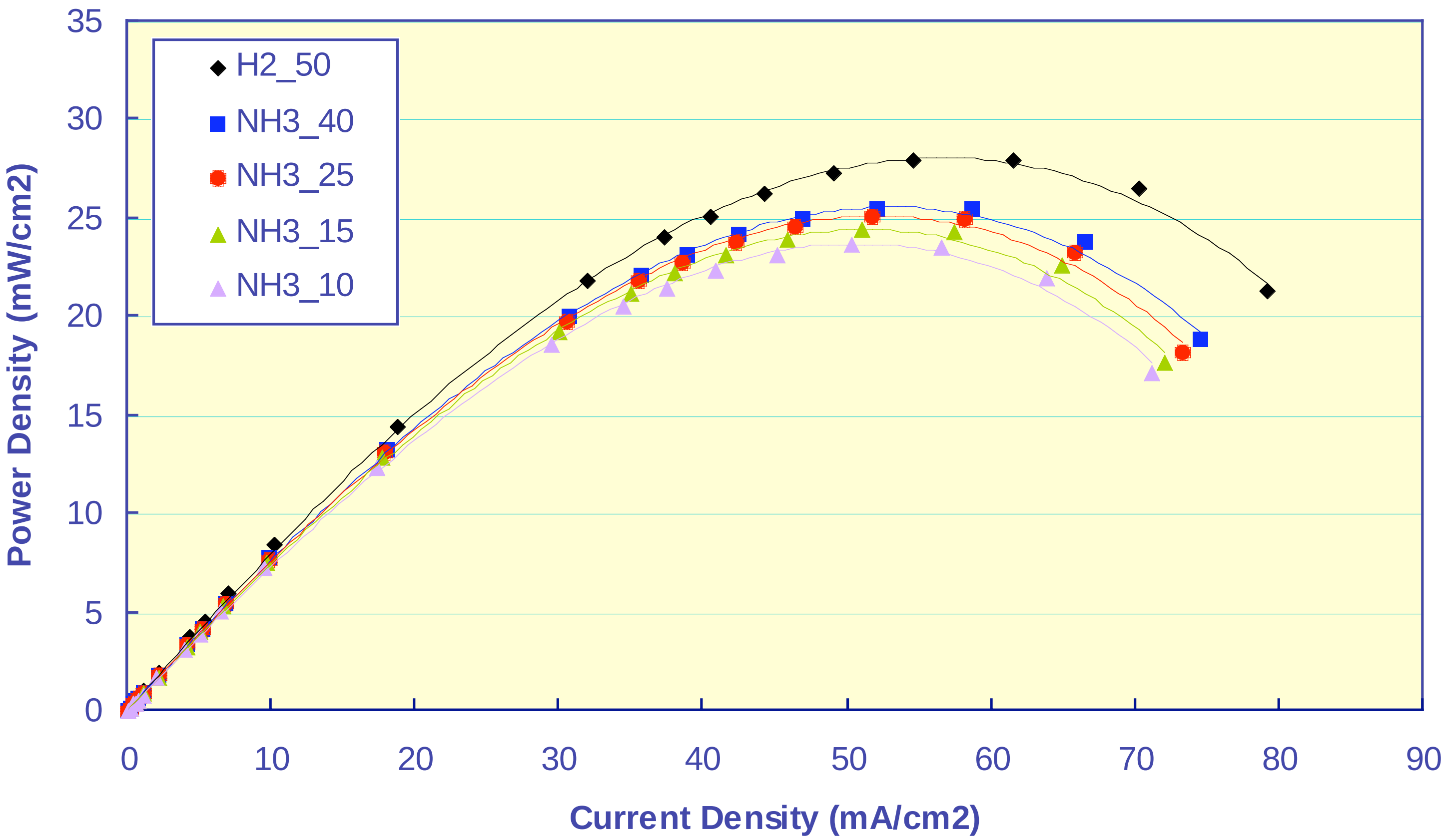
Powder XRD patterns of BCG calcined at 1350°C (a), sintered at 1500°C (b), 1550°C (c), 1600°C (d), 1650°C (e).

Pt/BCG/Pt Ammonia Single Cell Fuel Cell



J. Electrochemical Society, 2004, 151(6), A930

Pt/BCG/Pt Ammonia Single Cell Fuel Cell



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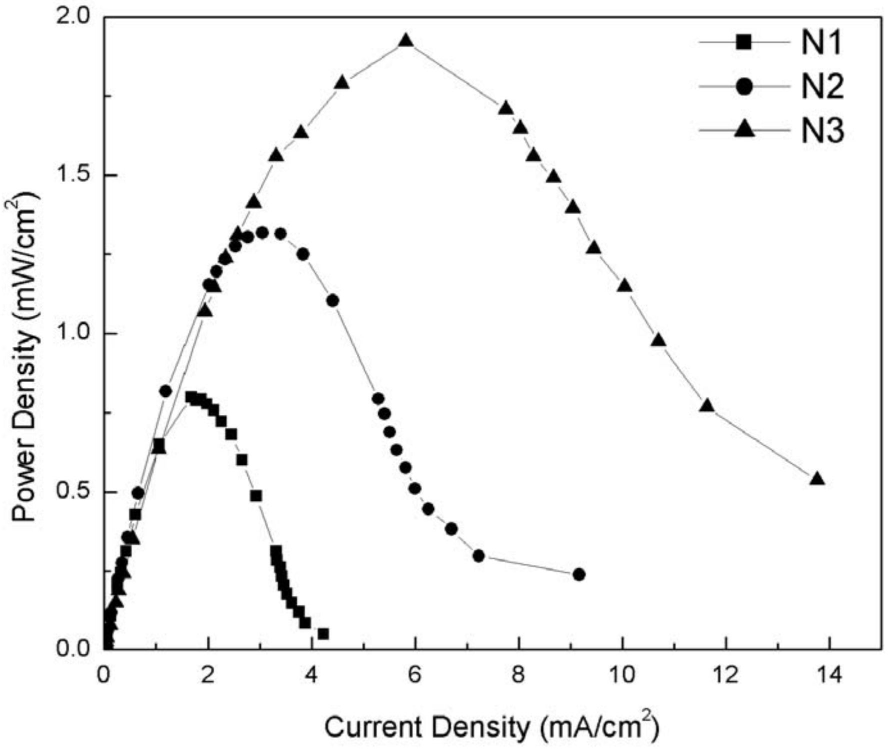
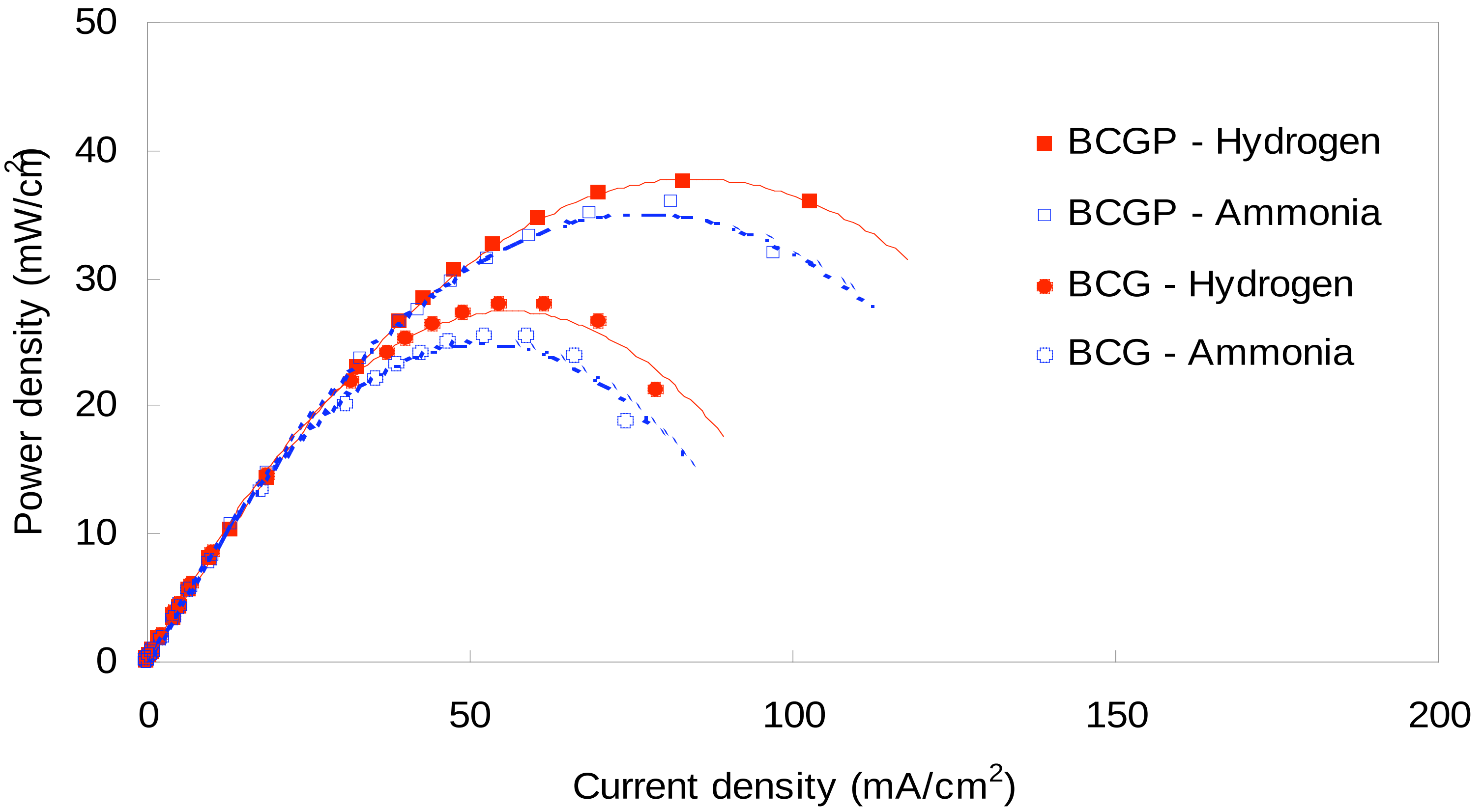
Cathode Performance Characteristics for Series of Cells

N1= NiO-BCG/BCG/Pt
N2=NiO-BCG/BCG/LSC
N3=NiO-BCG/BCG/LCFC



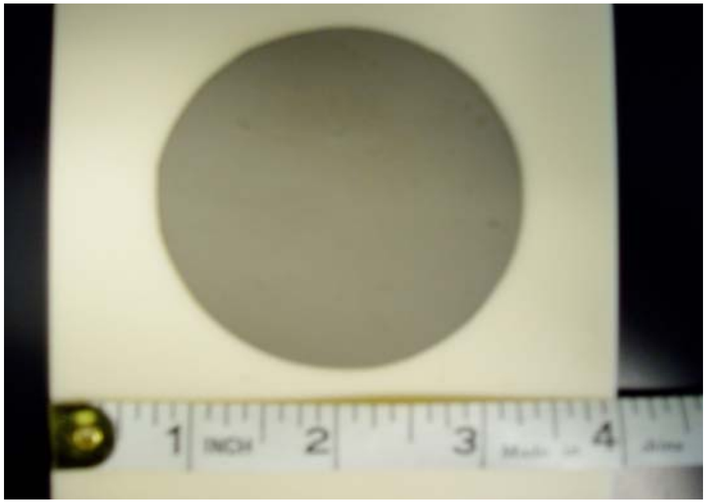
J. Power Sources 2004, 136, 24

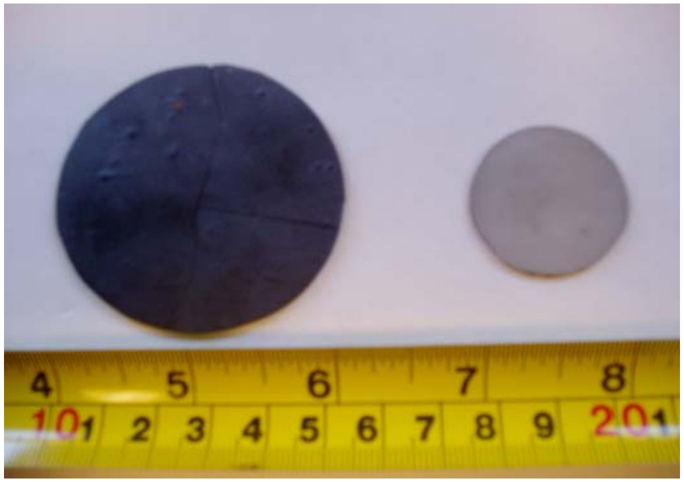
Doubly-doped $BaCe_{0.8}Gd_{0.19}Pr_{0.01}O_{3-*\delta}$ Electrolyte



J. Power Sources 2005, 140, 264

Tape Casting of BCGP Electrolyte Materials





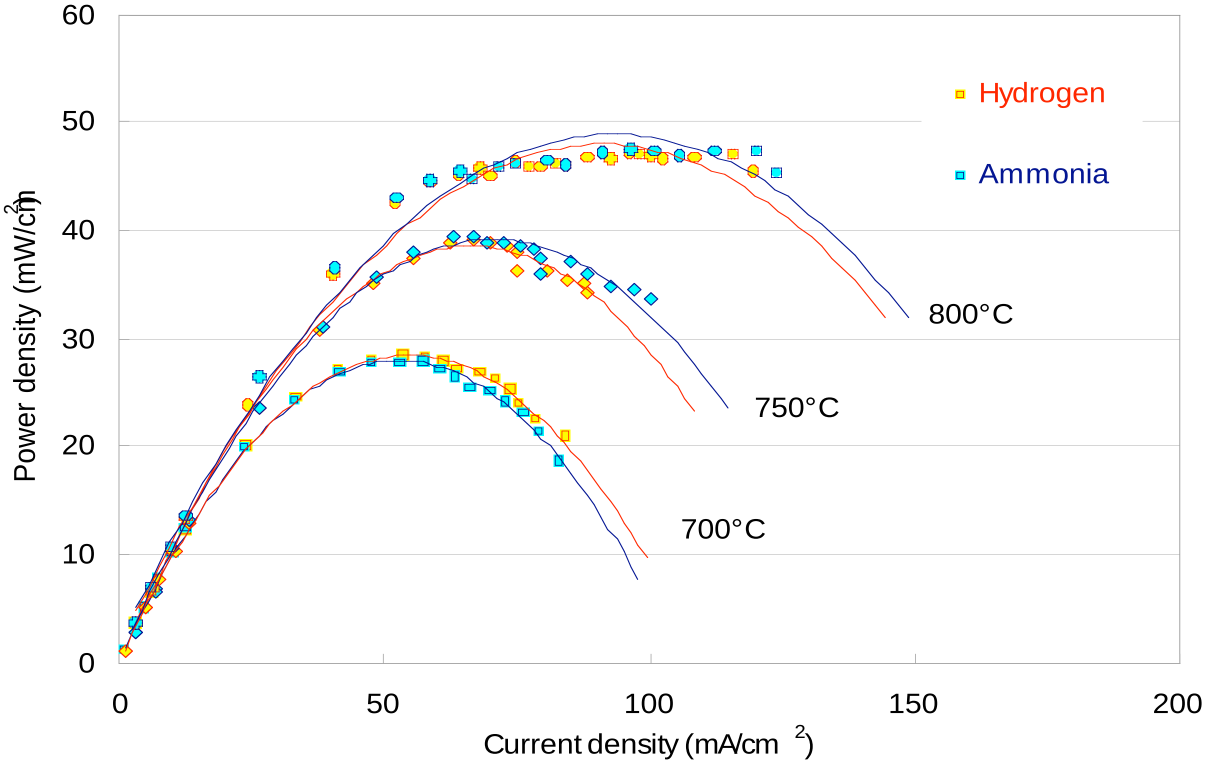
A green 2” dia BCGP disc formed by tape casting

2” and 1” dia. BCGP discs after sintering

R&D Activities Using Commercially Available Conventional SOFC Materials

Direct Ammonia Fuel Cell Using Commercial O^{2-} Conducting Electrolyte

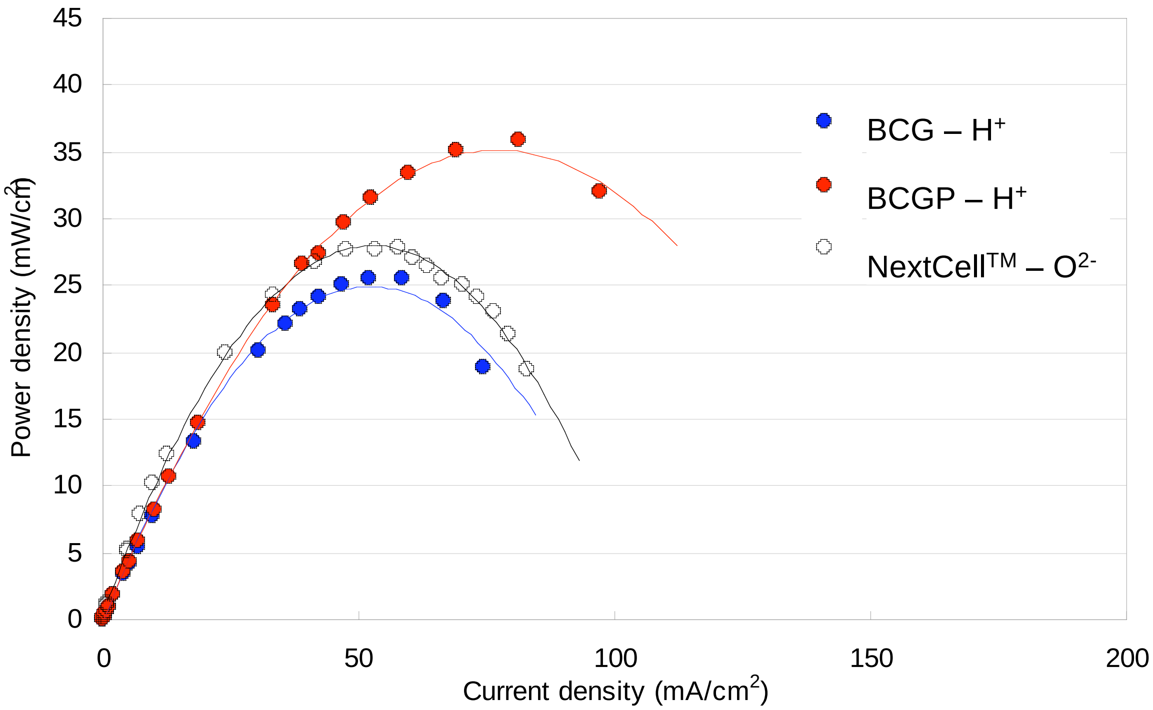
- Performance is stable at a given operating temperature regardless of fuel.
- Power densities are similar whether with ammonia or hydrogen.



Proton Conducting vs O^{2-} conducting Electrolytes for SOFC

- Compares proton conducting (in-house) and oxygen ion conducting (commercial) materials at 700°C in ammonia.

- Due to their higher conductivity, proton conducting electrolyte materials can operate at lower temperatures than O^{2-} conducting materials.



Commercial Opportunities for Direct Ammonia Fuel Cells

In stationary distributed power generation:

UPS for Critical Ammonia Refrigeration:

- Experienced in handling ammonia
- Market is expanding due to shift to environmentally friendly refrigerants
- Insatiable power requirement
- High overall efficiency in CHP cycles
- Requirement for uninterruptible power

We are currently talking to a Canadian fuel cell manufacturer and ammonia producers about doing a collaborative field trial.

In transportation:
Railway Locomotives?

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