Canadian Advances in Thermochemical H_2 Production in the Context of Conventional Electrolysis

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Canada

AECL
Atomic Energy of Canada Limited
EACL
Énergie atomique du Canada limitée

Outline

The market for hydrogen

SMR vs LTE

The GIF context

AECL work on sulphur thermochemical cycles

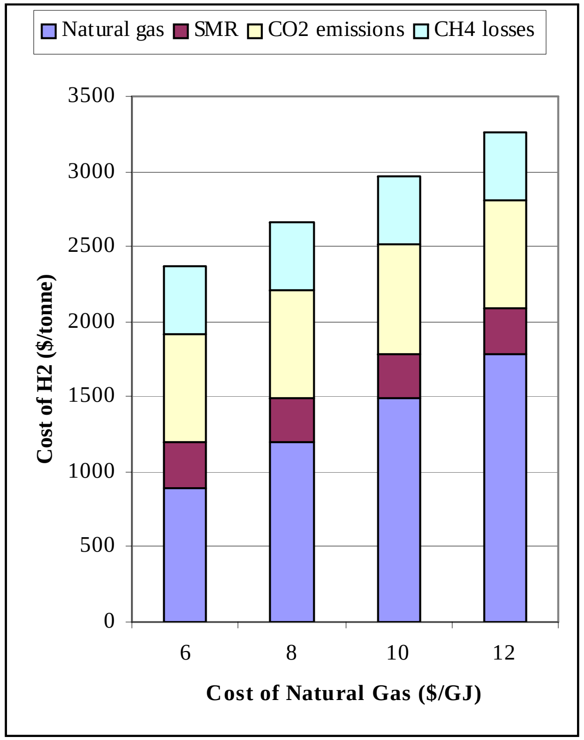
Collaboration with USDOE on copper chloride cycles

Where will the demand be?

- Fuel for road vehicles?
  - Later perhaps but uncertain
    - Depends on battery vs fuel cell development
- More likely for larger vehicles (trains, ships)
- Big market is for upgrading petroleum
  - Exists and is growing rapidly
    - Especially in the oil sands developments in northern Alberta
  - Needs 3 to 5 kg H_2/bbl
  - Expect over 2 million bbl/d by 2015
  - 1 GWe = 160 000 bbl/d

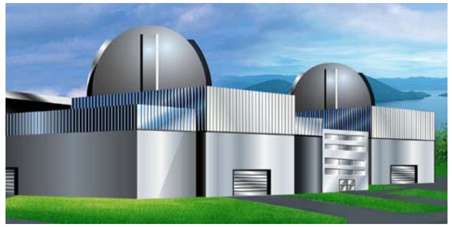
How will H_2 be made?

- Conventionally come from natural gas by SMR
  - Cost has risen fast
    - Realistic to base on oil:gas at 6:1
    - Add 70 \$/t CO_2
    - Add 3% leakage of CH_4 from well to end use
  - Supply of natural gas is uncertain
    - All Mackenzie pipeline output could go to oil sands upgrading
- Need a new way
  - High-temperature thermochemical?
  - High-temperature electrolysis?
  - Conventional low-temperature electrolysis?

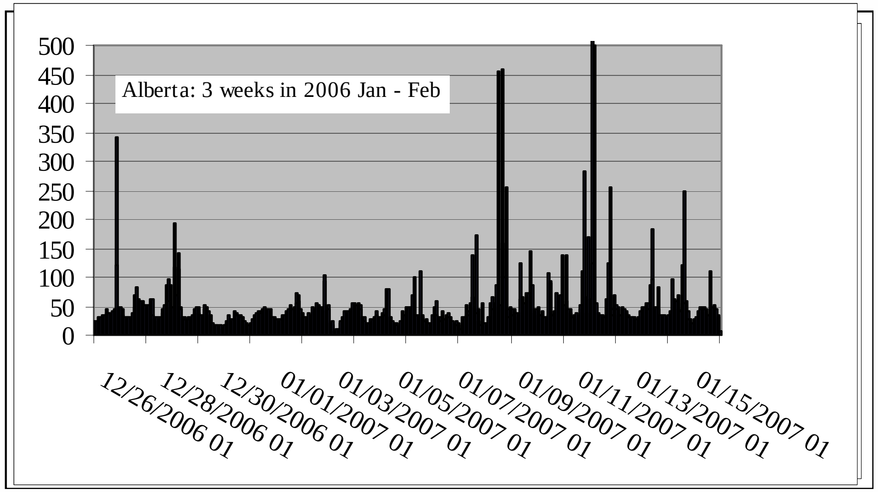


LTE will be available much sooner

- Make it using Generation III+ reactors
  - Could be deployed by 2015



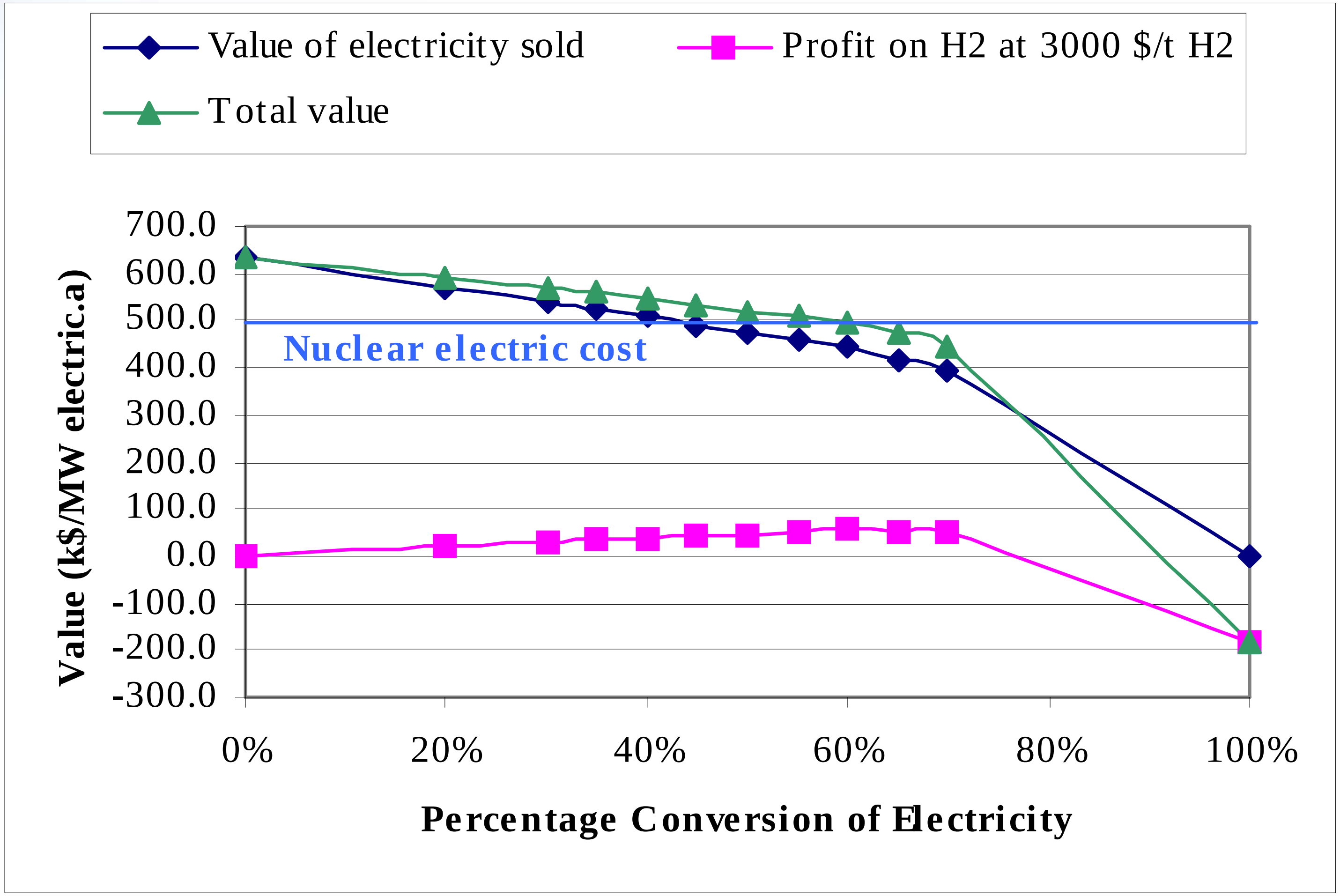
- Key is to produce H_2 with off-peak electricity
  - Preferably with variable-current cells
  - Needs large-scale storage
    - In salt caverns



⇒ Alberta case

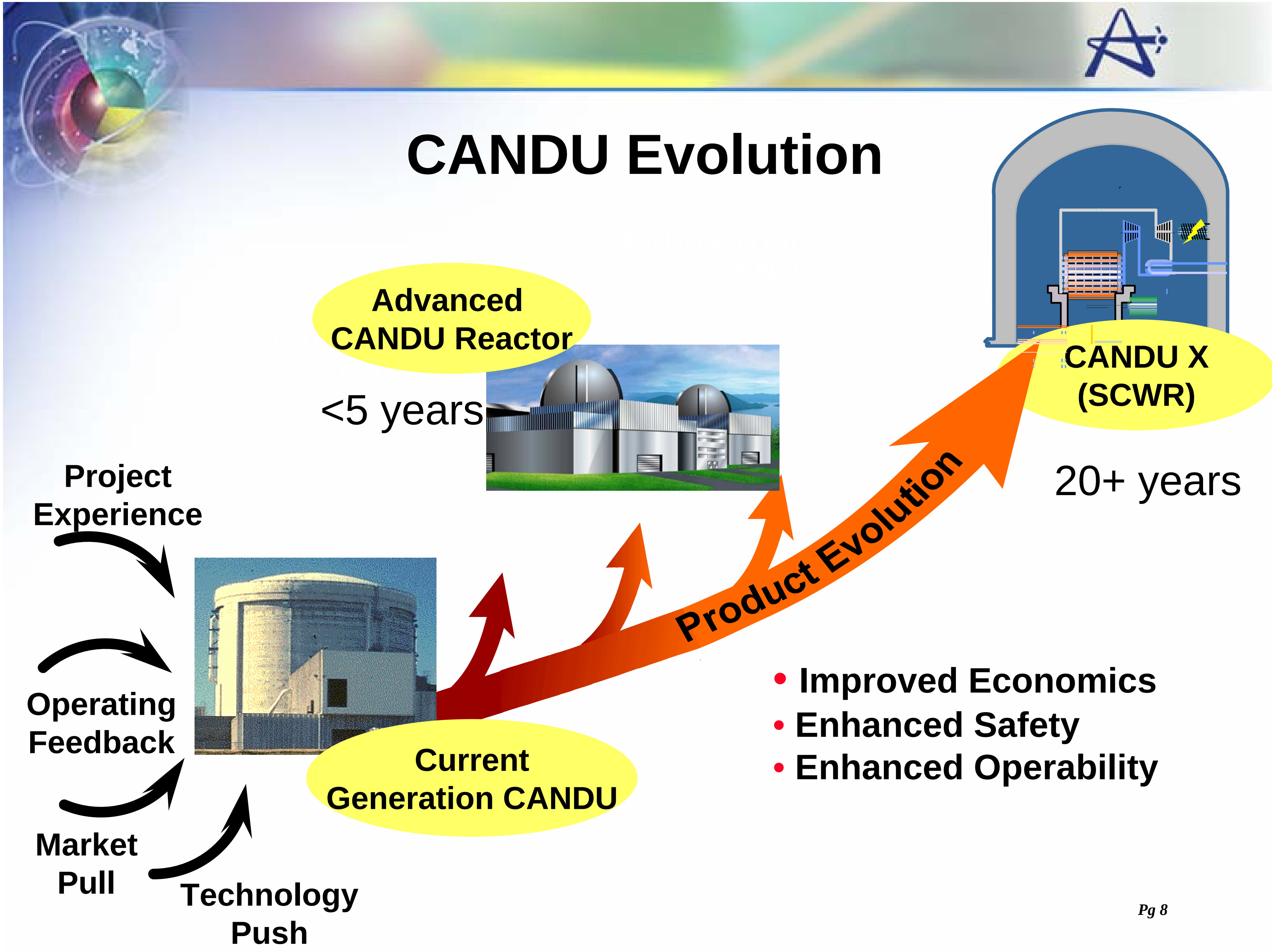
- 550 $/kW cells
- 5000 $/t storage
- Applying real-time Alberta power prices

Intermittent H_2 Production



And later?
Within the GenIV, Canada focuses on SCWR with crosslink to VHTR

Acronym		*Spectrum*	*Fuel cycle*
SFR	Sodium Cooled Fast Reactor	Fast	Closed
LFR	Lead Alloy Cooled Reactor	Fast	Closed
GFR	Gas Cooled Fast Reactor	Fast	Closed
VHTR	Very High Temperature Reactor	Thermal	Once-through
SCWR	Supercritical Water Cooled Reactor	Th. & F.	Once-t. & Closed
MSR	Molten Salt Reactor	Thermal	Closed


CANDU Evolution
Advanced CANDU Reactor
<5 years
CANDU X (SCWR)
20+ years
Product Evolution
Project Experience
Operating Feedback
Market Pull
Technology Push
Current Generation CANDU
• Improved Economics
• Enhanced Safety
• Enhanced Operability

CANDU SCWR Concept

- Started in 1994 as Candu X Program
- Establish the design limits and ultimate potential
- Main CANDU features are retained.
  - Horizontal modular channels.
  - Heavy water moderator.
- Supercritical light water coolant (higher efficiency).
- Advanced fuel channel design (internal insulation without calandria tube).
- Options systematically studied
  - Mark 1: indirect cycle T_{out} ~ 400^{+} ^{o}C set by existing Zr
  - Mark 2: direct cycle T_{out} ~ 600^{+} ^{o}C set by existing turbine
  - Mark3: multiple cycle T_{out} >850 $^{+}$ ^{o}C set by known materials

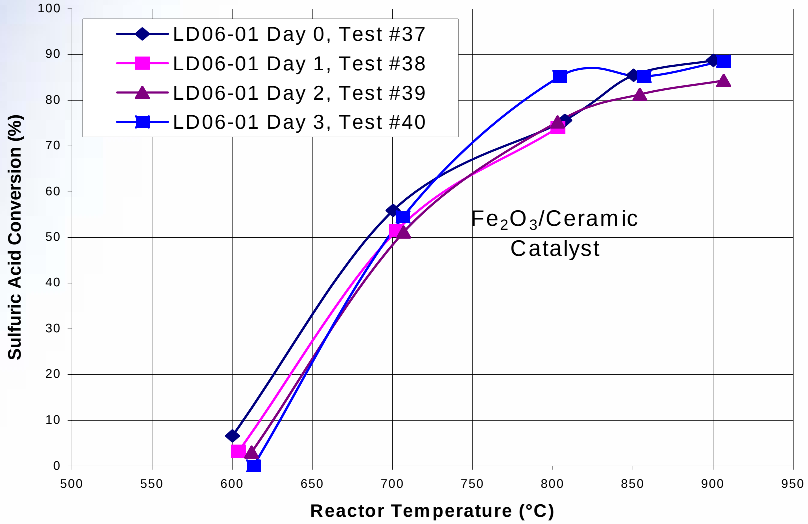
Thermochemical Work in Canada

In collaboration within the GIF and through I-NERI agreements with the USDOE

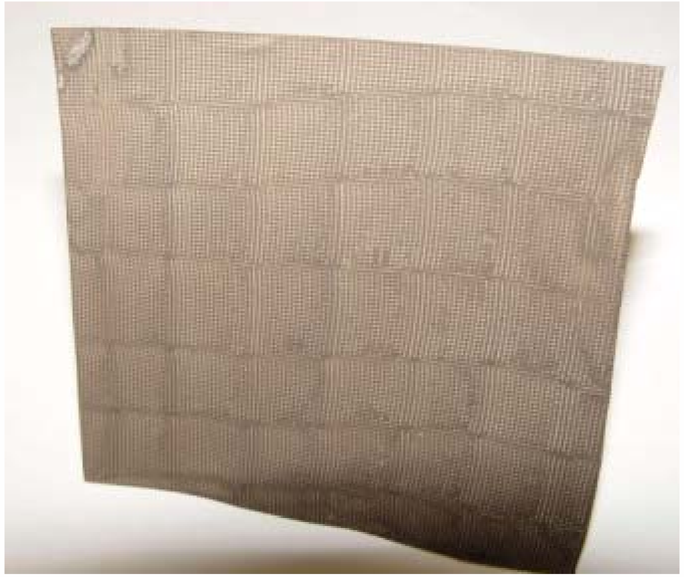
The H_2SO_4 Side of I/S and other S Cycles

- $H_2SO_4 \rightarrow SO_3 + H_2O$
  - Majority of energy; lower temperature (< 500°C)
- $SO_3 \rightarrow SO_2 + \frac{1}{2} O_2$
  - Minority of energy; higher temperature (> 700°C)
  - Could avoid a high temperature reactor by providing direct electric heating of a substrate on which catalyst deposited
  - Work so far on selecting catalysts

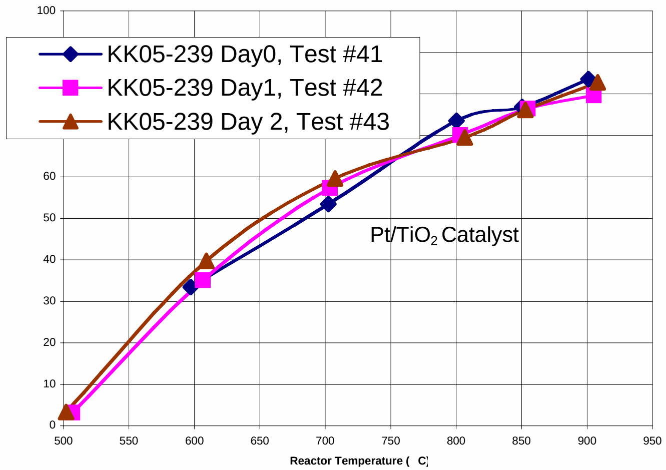
Assessing catalysts for SO_2 decomp.



Fe catalyst



A metal (textured Inconel 800) sheet coated with catalyst for SO_3 decomposition



Pt catalyst

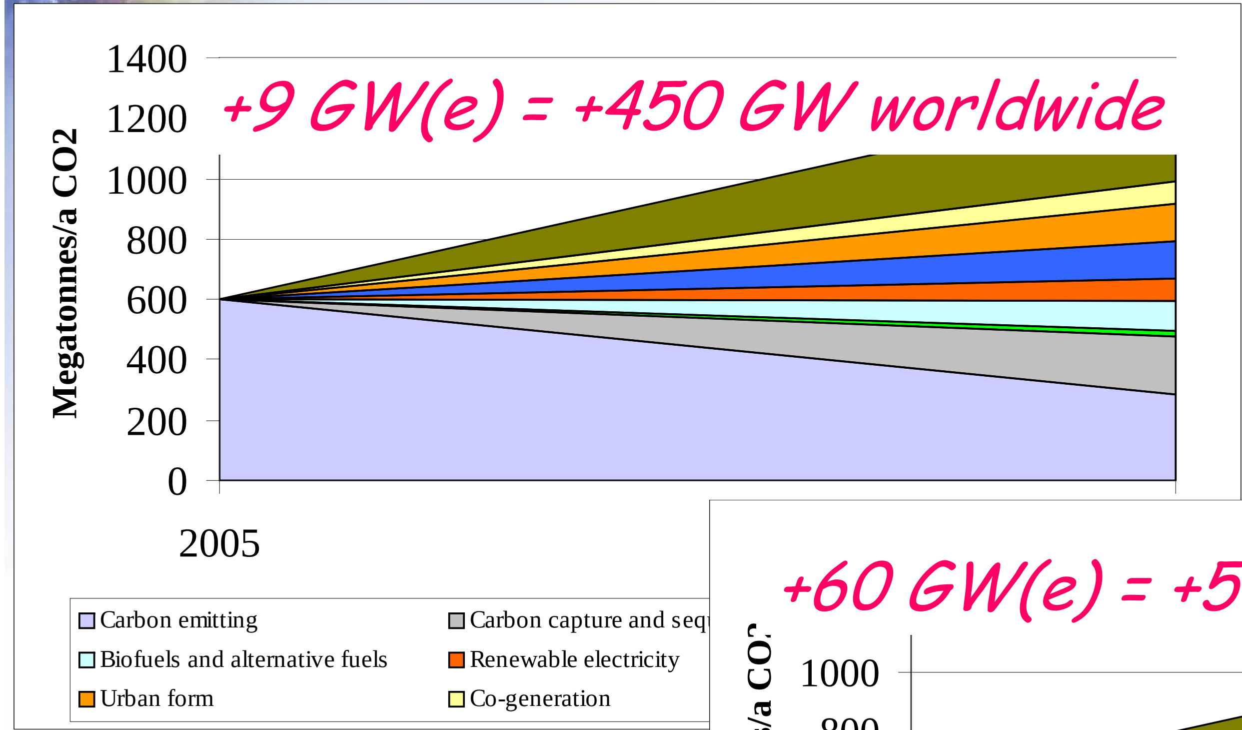
Copper chloride cycles

- Work led by USDOE at Argonne (Michelle Lewis)
- AECL is currently focused on the electrochemical step

#	Reaction Stoichiometry	Temperature (°C)
1	$2Cu + 2HCl(g) \rightarrow 2\ CuCl(l) + H_2(g)$	425-450
2	$4CuCl(s) \rightarrow 2CuCl_2(a) + 2Cu$	<100
3	$2CuCl_2(s) + H_2O(g) \rightarrow Cu_2OCl_2\ (s) + 2HCl(g)$	300-375
4	$Cu_2OCl_2\ (s) \rightarrow 2CuCl(l) + ½O_2(g)$	450-530

- Or a variant on reaction #2: $2\ CuCl + 2\ HCl \rightarrow 2\ CuCl_2 + H_2$
  - Avoids solid phase
  - Preliminary testing yields H_2 from both reactions at ~ 0.65 V

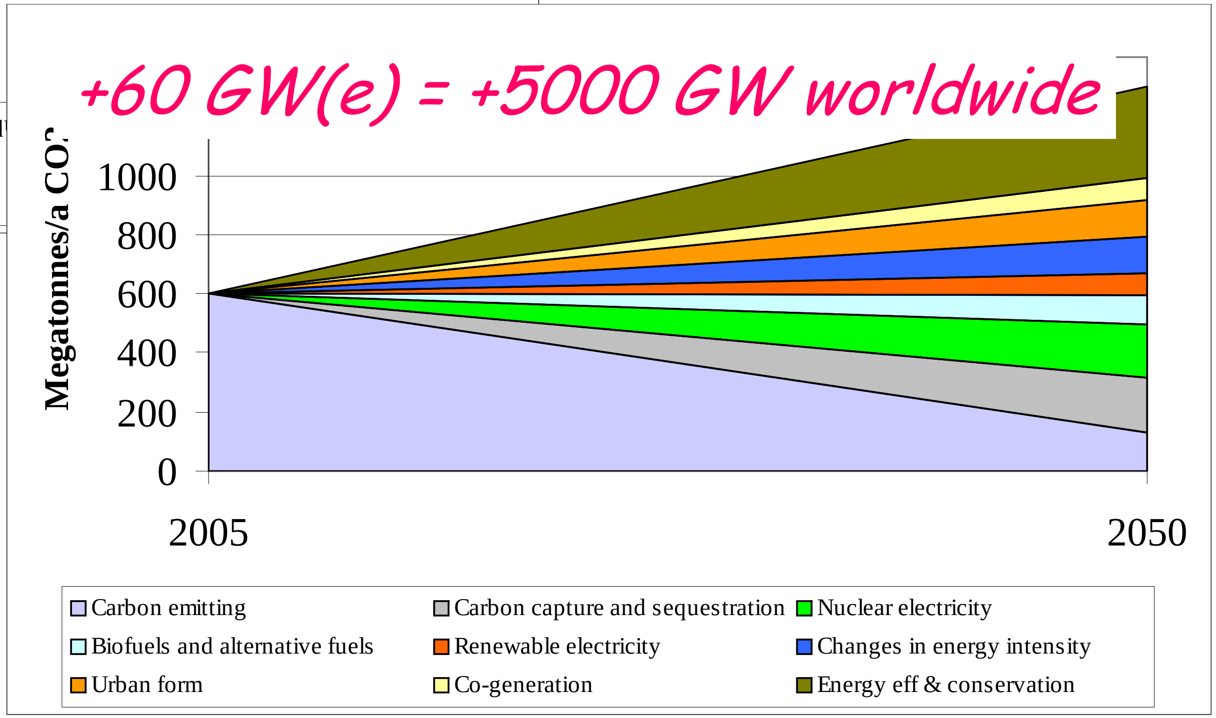
Placing Canada in Global Context



As in NRTEE:

⇐ 50% reduction

NRTEE + large nuclear deployment: 75% reduction ⇒



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