Hydrail: a Building Block for Energy Delivery in a Low-Carbon World

Alistair I. Miller
Researcher Emeritius
Atomic Energy of Canada Limited
Chalk River Laboratories

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Canada

AECL Atomic Energy of Canada Limited

EACL Énergie atomique du Canada limitée

Which transport form for H_2-power?

Feature	cars	truck	plane	train	ship
• Few operators	1	2	4	5	3
• High utilization factor	1-2	4	4	4-5	5
• Steady load	2	3	2-4	3	5
• Not too dispersed	1	2-4	4	5	3-4
• H_2 volume unimportant	1	3	3	5	5
• Weight important	3	3	5	1	1
• Good control of H_2	1	2	5	5	5
• Minimal public anxiety	1	4	1	5	5
• TOTALS	11-12	23-25	28-30	33-34	32-33



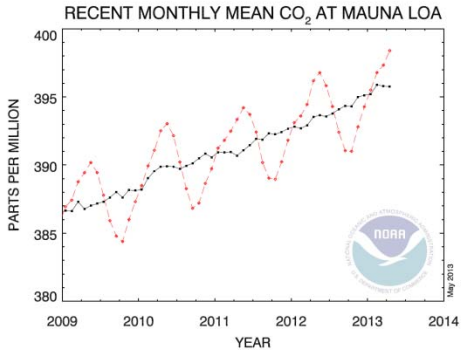


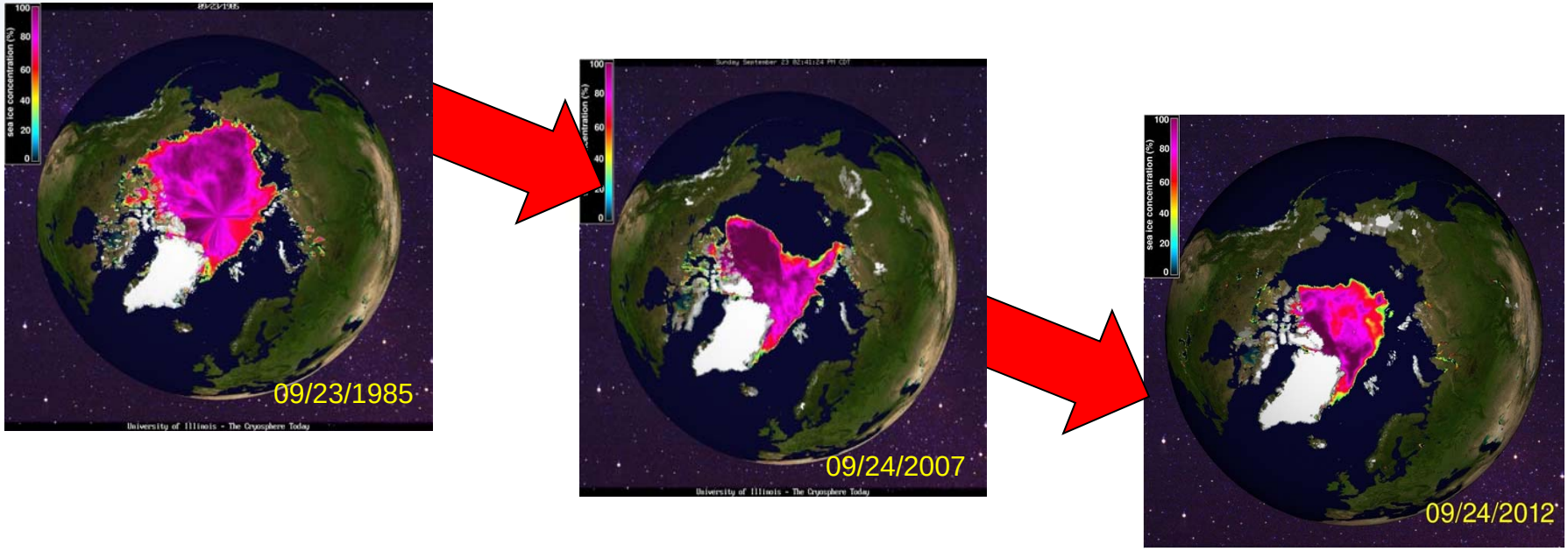




Still true, but exactly 4 years later

- Global CO_2 emissions risen 8.2% in 4 years
  - Despite Global recession
  - Though N.A. dropped 6.7%
- Atmospheric CO_2 has exceeded 400 ppm





And CO_2 is acidifying our oceans

What, How and Where

- What's gone wrong?
  - Population growth and growing energy demand from emerging economies
  - Denial or band-aid solutions, blinkered vision
- How do we fix it?
  - Delivering deep cuts to CO_2 emissions to stabilize atmospheric CO_2 level: i.e. at least 80% reduction by developed economies
    - Minor tweaking will not deliver this
- Where does hydrail fit?
  - Displacing oil and truck transport
  - Making rail track electrification affordable
  - Providing storage for electrical energy
    - *Provided electricity generation is non-CO_2-emitting!*

2001: where the energy went – and next?

The view in 2009.

	Oil (Mt)	Natural Gas (Mtoe)	Coal (Mtoe)	Nuclear Energy (Mtoe)	Hydro electric (Mtoe)	Total (Mtoe)	Population (millions)	toe/person	Consumption at Half European Rates (Mtoe)
USA	896	555	556	183	48	**2237**	293	7.6	**502**
Canada	88	65	29	17	75	**275**	32	8.6	**55**
Europe	760	423	344	225	142	**1895**	553	3.4	**947**
Asia/ Pacific	973	275	1021	115	129	**2512**	3752	0.9	**6913**
World	3511	2164	2255	601	595	**9125**	6348	1.4	**10874**

Conservation isn't enough; we need a 60% cut in carbon emissions globally

Today's update: where the energy went in 2011

	Oil (Mt)	Natural Gas (Mtoe)	Coal (Mtoe)	Nuclear Energy (Mtoe)	Hydro electric (Mtoe)	Total (Mtoe)	Population (2013 millions)	toe/person	Consumption at Half European Rates (Mtoe)
USA	834	626	502	188	74	**2269**	314	7.2	**538**
Canada	103	94	22	21	85	**330**	34.5	9.6	**59**
Europe	739	527	377	232	137	**2096**	595	3.5	**1019**
Asia/ Pacific	1316	532	2553	108	248	**4803**	4342	1.1	**7436**
World	4059	2906	3724	599	792	**12275**	7089	1.7	**12140**

Totals include 1.6% worldwide of renewables in 2011

Percent change 2001 to 2011

	Oil (Mt)	Natural Gas (Mtoe)	Coal (Mtoe)	Nuclear Energy (Mtoe)	Hydro electric (Mtoe)	Total (Mtoe)	Population (2013 millions)	toe/person	Estimated fuel CO_2 emission changes
USA	-7%	13%	-10%	3%	54%	1%	7%	-5%	-4%
Canada	17%	45%	-24%	24%	13%	20%	8%	11%	+14%
Europe	-3%	25%	10%	3%	-4%	11%	8%	4%	+6%
Asia/ Pacific	35%	93%	150%	-6%	92%	91%	16%	23%	+103%
World	16%	34%	65%	0%	33%	35%	12%	24%	+38%

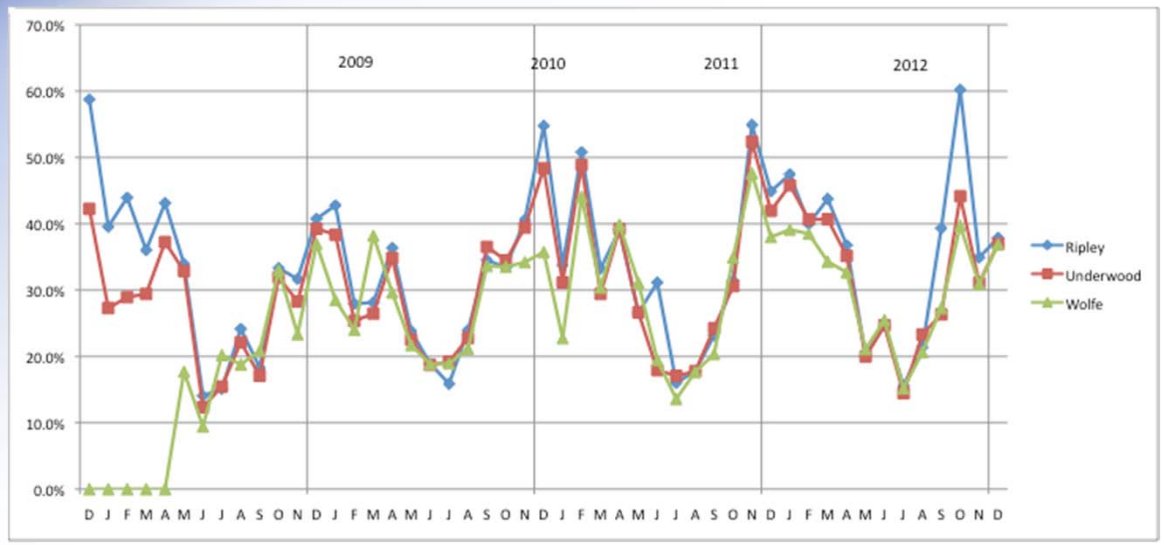
Thomas Robert Malthus (1766 – 1834)

- Populations grow geometrically
  - 1 billion in 1800, growing about 25% every 50 years
- Resources grow linearly
  - Not really obvious why
- World population had been doubling every 40 years in the 20th Century but the rate is now slowing
- Was Malthus wrong or merely premature?
  - Technology?
  - Energy
    - Wind and water @ ~25 kJ/t
    - Coal, oil, natural gas
      - Coal = 900 Gt @ 25 GJ/t
      - Used about 6% or 1 300 EJ of 22 000 EJ available
    - Uranium/thorium = 40 Mt @ 100 PJ/t = 4 000 000 EJ

What are our energy options?

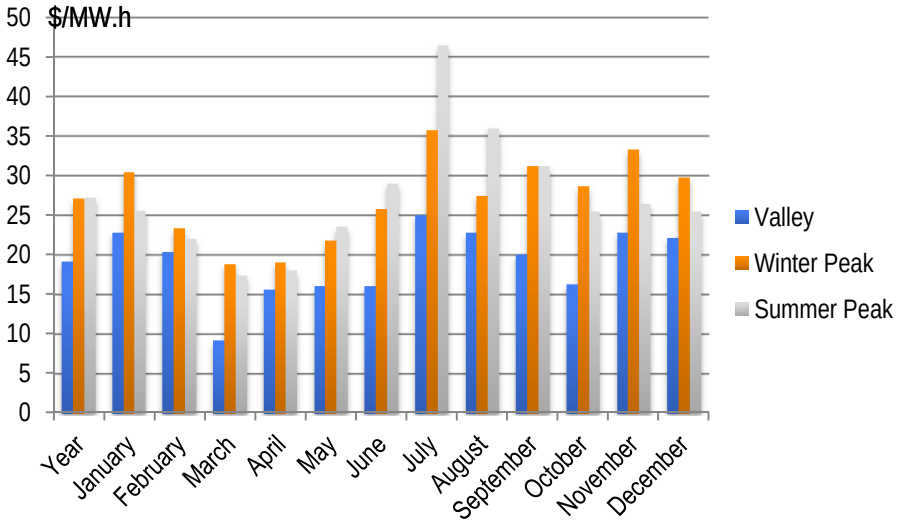
- All sourced from the stars:
  - Instantly but variably as direct sunlight
  - Ephemerally as wind
  - For the order of a year as hydraulic energy
  - From the order of a year to a century as biomass
  - Over tens of millions of years as fossil fuels
  - From 4.5 billion years ago as fission energy
  - And maybe some day from the Big Bang as fusion energy
- Available now:
  - Sunlight is big
    - 2.7 ZJ/a (at surface) or 1.5 hours worth of actual annual consumption
  - All coal reserves = 3.2 days of sunlight
  - All mineable uranium and thorium = 1.8 years of sunlight
    - Excludes seawater

Wind's limitations



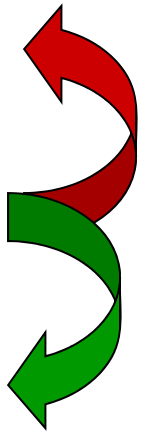
Data of three long-running Ontario windfarms
- IESO web site

AECL's NuWind® concept combines nuclear and wind to make and store off-peak hydrogen



Energy density varies

- Wind or falling water
  - ~ 0.000025 GJ/tonne
- Coal, oil, natural gas
  - ~ 25 GJ/tonne
- Uranium or thorium
  - ~ 100 000 000 GJ/tonne
  - ~ 600 000 GJ/t in today's reactors



Which way?

- Material to be processed and/or wastes to be disposed off are inversely proportionate to energy content
- One 1 GW reactor = ~ 9 km^2 of solar collector area

Transportation: oil versus electricity

- Transportation is more than a quarter of all energy use and growing
- Overwhelmingly reliant on oil
  - 90 $/bbl today; increasing cost for new production will drive higher
  - Think of one litre of gasoline or diesel (energy content of ~ 0.26 kg H_2)
    - ~75 ¢/L (without tax) — 30 000 kJ = 8.3 kW.h
    - Used with 25 to 40% efficiency — Delivers 2.1 to 3.3 kW.h — 36 – 22 ¢/kW.h
    - If add 70 $/t CO_2, additional 15¢/L — 51 – 37 ¢/kW.h
- Electricity
    - Say, 20 cent/KW.h at retail level
      - Used as battery electricity with at least 75% efficiency — 27 ¢/kW.h
- Hydrogen (electrolytic)
    - Electricity applied close to source at off-peak rates (bought by grid), $3.30/kg H_2
      - 1 kg H_2 = 33 kW.h (LHV)
      - As gas, conversion efficiency at 0.4 — 25 ¢/kW.h
      - As liquid, adds 30% more energy — 33 ¢/kW.h
- At 90$/bbl, H_2 looks competitive if a realistic CO_2 cost is included for oil
  - For light vehicles, batteries will likely win over distributed H_2 for cars
  - For heavy vehicles with centralized fueling, H_2 is interesting

The Hydrail concept is not new

- Foster & Escher, ERDA, 1976
- English *et al.*, Canadian Institute of Guided Ground Transport, 1978
- Transport Canada, 1983
- Scott & Rogner, *Int. J. Hydrogen Energy*, 1993
- Stehley, Taylor & Peters, US Transportation Research Board, 1994
- Miller, AECL-12044, 1999

However, sometimes the obvious needs to be repeated and repeated

Finally, the world seems ready to tackle the GHG emissions crisis

The Train arriving at platform #2 could be a Hydrail

Outline

- Trains have been somewhat out of fashion but:
  - would be relatively easy to convert to hydrogen as fuel
    - The hydrogen (H_2) must come from a non-GHG emitting source
      - The traditional way of making hydrogen, Steam-Methane Reforming, is only effective if CO_2 is sequestered and there are minimal losses of CH_4
      - Sequestration, as usual, remains in the concept development phase
    - In most instances, the H_2 approach is far cheaper than electrifying track
    - H_2 fueling has almost limitless flexibility: trains can roam freely
  - adapt readily to fuel cells but fuel cells aren't necessary
  - GHG reduction could be amplified by encouraging switch from trucks to rail
    - Trucks use 2.5 to 4 times more diesel than rail
    - Cutting road freight would enjoy great public support

Trains first; other modes can follow

- Overall:
  - rail is obvious place to launch hydrogen fuel
  - ships are not bad but they wander
  - apart from the (very real) weight advantage, planes come out poorer than ships
  - trucks are poorer
  - Cars and other light vehicles are far behind

- Trains are an easy niche to start with

Evolutionary opportunities

- Begin in high-use corridors
- Only 4% of GHG transport emissions are from rail but 23% from commercial trucks
  - There is scope for a double win by further promoting inter-modal freight
- Can start with H_2-fueled diesels if fuel cells are not sufficiently developed
  - Technically, fuel cells are still nearly ready but are still expensive
- Many trains use at more than one locomotive so have important natural redundancy for a new technology

Hydrail versus electrified track

- Hydrogen at $3.30/kg has a cost advantage over $90/bbl oil
- Track electrification is very expensive
  - e.g. 700-mile Windsor to Quebec City corridor in Canada
  - Capital cost of electrification estimated at 1 to 3 billion dollars
    - UK West Coast upgrades inc. electrification cost 9 billion pounds
      - London to Glasgow, 402 miles
  - With straight electricity, cannot apply off-peak power
  - Electrification installation is disruptive over years
- Hydrail
  - Is flexible
  - Uses off-peak electricity
- But we need to place a realistic cost on CO_2 emissions

Hydrail's advantages over electric trains

- Fuel cell or diesel/H_2-powered locomotives can roam
  - the system can grow without major commitments to new lines
  - unlike electrification, needs no critical traffic density to justify
  - Avoids either a totally new track or much interference with existing traffic while electrifying
  - Makes it easy to begin with a few prototypes
- Power demand can avoid peak periods

Interesting progression if this were to evolve from ...

il

The ultimate in unobtrusive transport

- ✓ With LH_2 fuel cells: no more than a murmur of sound and almost zero GHG emissions
- ✓ A legacy our children could be proud of

Now fueled by hydrogen

BC Rail

Which planet was that?

AECL EACL

With the sweep of its vision, Hydrail can really switch the H_2 light on