DISTRIBUTED ENERGY/ENERGY FROM WASTE

USING FUEL CELLS

Brant A. Peppley
Director
Queen's-RMC Fuel Cell Research Centre

BIOMASS AND ENERGY FOR THE GREAT LAKES

QUEEN'S-RMC FCRC Fuel Cell Research Centre

But First a Crash Course on Fuel Cells

Brant A. Peppley
Canada Research Chair in Fuel Cells
Director
Queen's-RMC Fuel Cell Research Centre

QUEEN'S-RMC FCRC Fuel Cell Research Centre

A Sample of Types of Fuel Cells

- Proton Exchange Membrane (PEM, SPE(TM), PEFC)
  - Hydrogen - Air
  - Direct Methanol - Air
- Solid Oxide (SOFC)
- Molten Carbonate (MCFC, Direct Fuel Cell, DFC)
- Phosphoric Acid (PAFC)
- Alkaline (AFC)

PEM Fuel Cells: Forklift Truck Battery Replacement

Fuel cell powered material handling equipment for large warehouse operations have already shown a cost benefit

Convenient hydrogen refuelling

WalMart successfully field tested General Hydrogen forklifts

Two units field tested at GM and Fedex.
GM have shown there is a real cost benefit of using Hydrogenics fuel cell forklift trucks instead of battery power forklift trucks.

QUEEN'S-RMC FCRC

PEM Fuel Cells: Backup Power Systems

12 kW

20 minutes

Hydrogenics Awarded Supply Agreement From American Power Conversion to Deliver Up to 500 Fuel Cell Power Modules for Backup Power Applications

For e-commerce systems in urban centres this is the only practical power backup option

QUEEN'S-RMC FCRC

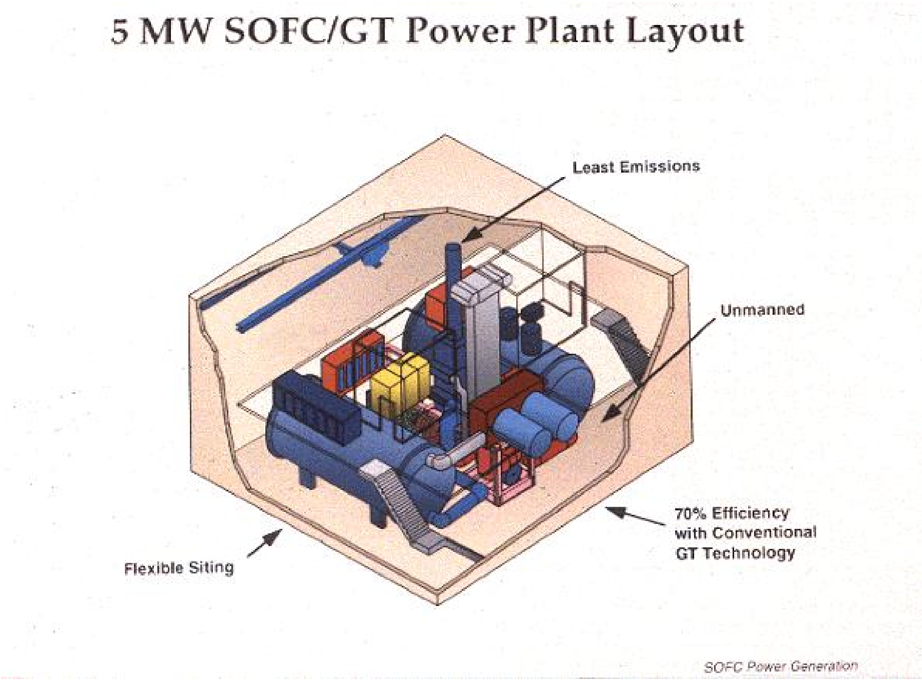
Honda Clarity FCX

Honda engineers estimated three years ago that its previous fuel-cell cars cost more than $1 million to build.

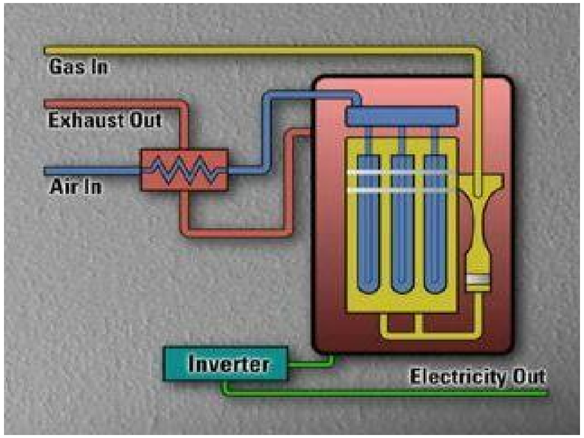
Duleep, who completed a fuel-cell vehicle study this year for the U.S. Department of Energy, believes Honda has cut its production costs to between $120,000 and $140,000 per vehicle.

[Honda to Deliver 200 Fuel-Cell Autos Through 2011 (Update2) – Bloomberg Japan Article May 21 2008]

Solid Oxide Fuel Cells: Stationay Power



- Five kilowatt residential SOFC system



- Five megawatt combined fuel cell / gas turbine power plant.

Waste heat at 1000ºC
Low cost ceramic and non-noble metal materials
Nat. gas/methane fuelled

QUEEN'S-RMC FCRC

Molten Carbonate / Direct Fuel Cell: Stationary Power

- Also well suited for distributed power market.
- High fuel-to-electricity efficiencies.
- Internal reforming = directly consume nat. gas / methane
- 650ºC(1200ºF) and atmospheric pressure = good quality waste heat.

QUEEN'S-RMC FCRC

Molten Carbonate

300 kW

1.5 MW

QUEEN'S-RMC FCRC

Phosphoric Acid: Small Stationary

200 kW
palletized systems

Nat. gas fuelled

QUEEN'S-RMC
FCRC

A carbohydrate economy?

- The most common energy currency on the planet, used by virtually every living thing, is the carbohydrate.
- Carbon is constantly recycled and is kept in balance in the system

Switchgrass

Fast rotation willow trees

QUEEN'S-RMC FCRC

Sources of Biomass

- Waste streams of carbohydrates
  - landfill
  - waste water treatment plants
  - wood waste
  - agricultural waste
  - other
- Virgin biomass
  - wood
  - grasses
  - **not corn!!**

QUEEN'S-RMC FCRC

Landfill Gas

- Approximately 55 million metric tons of carbon equivalent are released into the air each year by landfills
- More than 340 landfill-gas-to-energy sites in the US
- Typically use large reciprocating engines for combined heat and power systems
- Low methane concentration landfill gas often cannot be used for combustion engines but can still be used with fuel cells

QUEEN'S-RMC FCRC

Waste Water Treatment Plants

- Anaerobic Digestion generates high quality fuel (>50 vol% methane)
- Easily accessible and collection costs prepaid
- Methane is 23 times more powerful GHG than CO_2
- WWTP gas fuel cells systems would only supply a small fraction of our energy needs but would stop a significant amount of GHG emissions

Average WWTP ADG Composition
(from available data in Ontario)

Compound		
Methane (CH_4)	%	60.8
Carbon Dioxide (CO_2)	%	34.8
Hydrogen Sulphide (H_2S)	ppm	570
Oxygen (O_2)	%	1.5
Nitrogen (N_2)	%	2.4
Moisture (H_2O)	%	0.01
Carbon Monoxide (CO)	ppm	< 100
Hydrogen (H_2)	ppm	< 100
Silicon Compounds	ppm	0 - 2500

I.R. Wheeldon, C. Caners and K. Karan, Conference Proc BIOCAP, First National Conference, Ottawa, February 2005. www.biocap.ca/images/pdfs/conferencePosters/Wheeldon_I_P1.pdf.

QUEEN'S-RMC FCRC

Wood Waste

- Relatively large gasifiers already in operation
- Often located in remote locations where distributed power is needed

Burlington Electric Department, Vermont

	Pilot Data	McNeil Data
H_2	17.5	18.0
CO	50.0	47.0
CO_2	9.4	14.3
CH_4	15.5	14.9
C_2H_4	6.0	4.7
C_2H_6	1.1	1.1
HHV (MJ/Nm^3)	18.5	16.8

Comparision of McNeil Gasifier Gas Composition to Battelle Pilot Data [Paisley *et al.*, 2000]

Agricultural Waste

- Farm-based anaerobic digesters
- In 2002, 40 farm digester to energy projects in the US prevented 124,000 metric tonnes of CO_2 emission
  - 9 swine, 29 dairy, 2 poultry farms
- Commercial anaerobic digesters for farms are already available

Technical Feasibility of Biogas Fuelled Fuel Cells

- Numerous demonstrations have already proven the technical feasibility
  - phosphoric acid fuel cell (PAFC) on landfill gas
  - PAFC on waste water treatment gas (WWTG)
  - molten carbonate fuel cell (MCFC) on WWTG
  - solid oxide fuel cell (SOFC) on AD gas
- Most technical problems have been overcome
  - wide array of contaminants to clean up
  - high degree of variability in fuel quality

PAFC Demonstrations

- UTC Fuel Cells PC-25 currently in operation
  - Eight PC-25 systems in New York City (first in 1997)
  - One PC-25 in Köln-Rodenkirchen, Germany

- Portland, Oregon

200-kilowatt PC25 that converts anaerobic digester gas generated by the wastewater treatment facility into usable heat and electricity for the facility.

QUEEN'S-RMC FCRC

RWE Installation Rodenkirchen

Digester Gas (ADG)

PC25C Fuel Cell in the WWTP Rodenkirchen

Tech Data - Overview

Fuel Cell Type	PAFC / PC25C
Manufacturer	UTC Fuel Cells (formerly ONSI)
Power Output	200 kW
Usable Heat	225 kW
Electrical Efficiency	37%
Thermal Efficiency	45%
Size and Weight	5,5 m x 3 m x 3 m ca. 20 t

Stahl, Knut - Experiences from the PAFC Operation with Sewage Gas 3rd BFC Net Workshop Jan. 2005. http://www.bfcnet.info Downloads.

Performance Verification Report – PAFC

Results of 30 day test program for a PC25C Operated by NY Power Authority May - June 2004

Test Condition (Power Setpoint) (kW)	Electric Power Generated		Heat Prod'n Performance		Potential CHP Effic (%)
	Power Del'd (kW)	Effic (%)	Heat Produced (kW)	Effic (%)	
200	193.1	36.8	298.3	56.9	93.8
150	152.3	38.2	205.2	51.5	89.8
100	101.5	37.4	140.1	51.7	89.0

Greenhouse Gas Technology Center, EPA, Environmental Technology Verification Report, September 2004, www.sri-rtp.com/PC25_VR_final.pdf.

QUEEN'S-RMC FCRC

MCFC System on Wastewater Treatment Gas

1 Megawatt

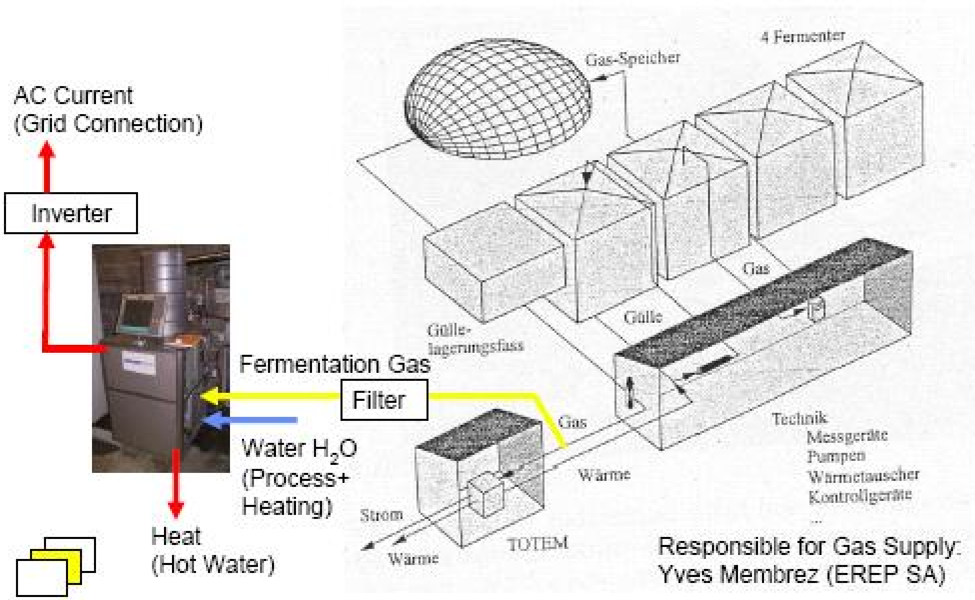
May 4, 2005
News Release

King County earns national environmental award for generating electricity from waste water treatment plant methane gas

QUEEN'S-RMC
FCRC

SOFC Demonstrations

- Limited number of installations
  - 1 kW experimental demonstration on fermentation gas



Implementation of SOFC system into biogas plant CHABLOZ in Lully

http://www.bfcnet.info/downloads/Jenne.pdf

QUEEN'S-RMC FCRC

Technical Challenges

Gas Clean Up

- Contaminant removal requirements are highly dependent on type of fuel cell used and the type of biomass. H_2S, organic acids, siloxanes, alkali metals, halogens.
- PAFC clean up system has been successfully demonstrated and a performance verification report published.
- PAFC more sensitive to poisons than SOFC and MCFC

Greenhouse Gas Technology Center, EPA, Environmental Technology Verification Report, UTC Fuel Cells PC25C Power Plant – Gas Processing Unit Performance for Anaerobic Digester Gas, September 2004, www.sri-rtp.com/GPU-VR-final.pdf

QUEEN'S-RMC FCRC

WWTP ADG Clean Up Requirements

Compound		
Methane (CH_4)	%	60.8
Carbon Dioxide (CO_2)	%	34.8
Hydrogen Sulphide (H_2S)	ppm	570
Oxygen (O_2)	%	1.5
Nitrogen (N_2)	%	2.4
Moisture (H_2O)	%	0.01
Carbon Monoxide (CO)	ppm	< 100
Hydrogen (H_2)	ppm	< 100
Silicon Compounds	ppm	0 - 2500

QUEEN'S-RMC FCRC

Technical Challenges

Gas Clean Up

- H_2S clean up achievable with activated carbon. Can be made regenerable
- Frequency of carbon replacement is acceptable for low H_2S concentrations (<100 ppm)
- For higher concentrations a regenerable system with trapping is required **(needs work!)**
- **Siloxanes are a more serious problem!**
- In high temperature fuel cells siloxanes form glassy deposits

QUEEN'S-RMC FCRC

Technical Challenges

Gas Clean Up – Siloxane Removal

from Applied Filter Technology

- Siloxane removal is one of the more challenging aspects of using landfill or WWTP AD biogas
- Agricultural waste ADG does not contain siloxanes
  - – cows don't use cosmetics and conditioner!!

Biogas
Fuel Processing

- A fuel processor changes the composition of the biogas so that it can be fed to a fuel cell system to a hydrogen-rich mixture that can be fed to a fuel cell
- The process adds complexity to the system but usually is necessary in order to obtain acceptable fuel cell performance and lifetime.

Biogas Reforming – Technical Challenges

- Diluent and contaminant issues
  - in landfill site methane capture, problems can arise from excessive Nitrogen dilution
  - oxygen contamination can also result in poor reformer performance
- CO_2 Dilution
  - high CO_2 concentrations result in some dry reforming occurring in reformer
  - this can lead to carbon deposition (coking)
  - better catalysts that avoid coking are required

Economics of Biomass Fuelled Fuel Cell Systems: Issues

- Difficult to the predict cost of most fuel cells
- Valuation of carbon credits and assessment of GHG reduction? $2 - 50 per ton
  - The report found that the volume of credits trade rose 65 per cent year-on-year to over 65 million ton, while the average price paid to offset one ton of CO_2 rose from approximately four to six dollars. (AccountancyAge.com 15 May 2008)
- Duty cycles with large peak demands can dramatically increase cost and reduce efficiency. This has a negative effect the economics.

QUEEN'S-RMC FCRC

Valuation of Carbon Credit

100

- Even if we do know the value of a carbon credit how do we evaluate the actual GHG reduction

Relative GHG Emissions for Natural Gas and Various Biomethane Fuelled Fuel Cell Power Systems

Nilsson, L.J., and K. Ericsson
http://www.bfcnet.info/downloads

QUEEN'S-RMC FCRC

Limited Cost Data

- Portland OR reports having spent $1.3 million for their 200 kW PAFC system
- The mayor of New York City reports that eight 200 kW PAFC systems were installed at a cost of $13 million. Based on these numbers the average cost per unit is $1.6 million or $8000 per kW
- The initial cost of a landfill gas fuelled MCFC system was estimated to be US$1950-2350 per kW compared to US$1370 per kW for the gas engine.

Economic Feasibility

- The economics of biomass fuelled fuel-cell systems are still very difficult to assess. Even for PAFC systems that have had a long operating history the predicted cost per kW and the actual cost per kW can differ by a factor of two or three.
- The cost of the fuel cell is also very vague.
- Based on material costs SOFC stacks look very competitive
  - near term projected cost = US$400 per kW
  - the potential cost reduction with large-volume manufacturing methods is as low as US$180 per kW.

QUEEN'S-RMC FCRC

Conclusions

- Biomass-fuelled fuel cell systems are technically feasible and have been operated for extended periods with good reliability and performance
- Economic feasibility is much more difficult to assess but it appears that costs are too high
  - The impact of carbon credits on the economics of biomass fuelled fuel cell systems may be a significant factor in the near future.
- Utilising waste biomass for power generation will not solve our energy and GHG problems but it can significantly reduce GHG emissions

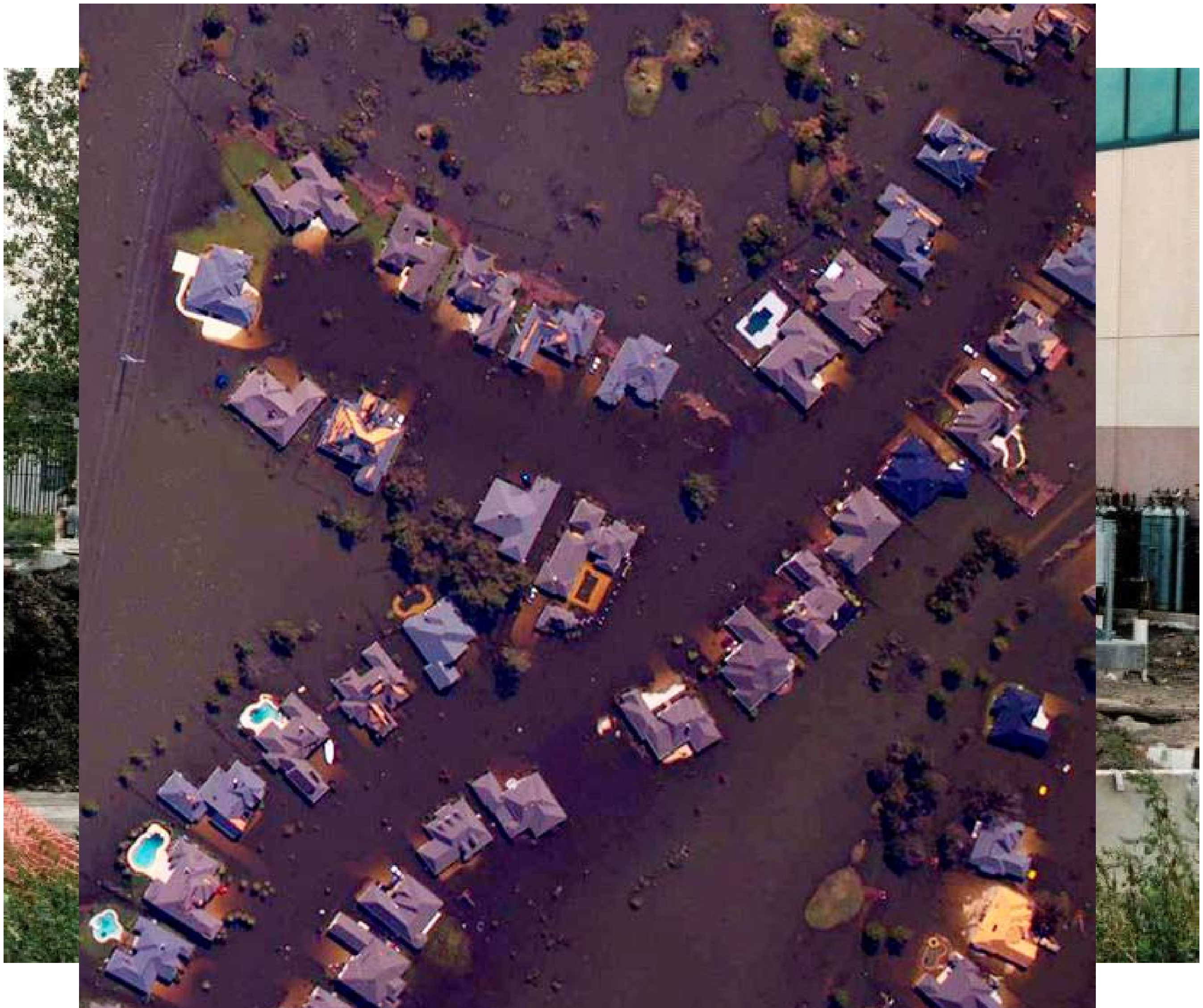
QUEEN'S-RMC
FCRC

New York City WWTP Fuel Cell Systems

Expensive, but they cost much less than …

QUEEN'S-RMC
FCRC

...dealing with disasters like New Orleans!



QUEEN'S-RMC FCRC

QUEEN'S-RMC FCRC Fuel Cell Research Centre

www.fcrc.ca

Brant Peppley
Director
Brant.Peppley@queensu.ca