Using Solid Oxide Fuel Cell to Increase Fuel Efficiency for Toronto Hospital

Authors: Yung Chi Cho, Sujit Gubbala, Zohaib Narejo, Zehra Hameed Reimoo and Mohammad Suria

Supervisor: Dr. Eric Crosiet

UNIVERSITY OF WATERLOO

Group 19

Motivation

Hospitals are large consumers of electricity and heat. Procuring these services through conventional means leads to high utility cost and carbon dioxide emissions.

Goal :

To design a system that

- Meets the electrical demand
- Utilizes waste heat
- Improves fuel efficiency
- Economically feasible

Hospital Profile Baseline

- 5 floor building accommodating 1121 people
- Annual electricity usage: 6.05 GWh
- Annual heating usage: 2.17MJ
- Acquires electricity from the grid
- Uses natural gas for space heating and hot water
- The annual CO2 emission from the hospital is 472 tonnes
- CO2 emissions by electricity: 276 tonnes
  by natural gas: 196 tonnes

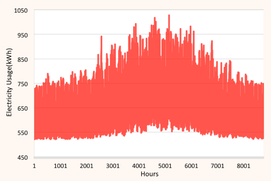


Figure 1: Total electrical load for a typical year

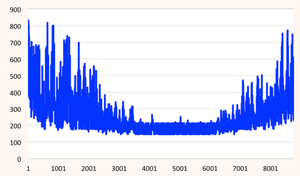


Figure 2: Total thermal load for a typical year

Data Source: Simulated hourly electricity and thermal load data for a typical hospital from a group working at CANMET Energy, Natural Resources Canada, Ottawa.

Why SOFC?

Solid Oxide Fuel Cell (SOFC) generates electricity through electro-chemical reactions. The operating temperature of SOFC ranges from 600 degree C - 1000 degree C.

The SOFC offers the following benefits:

- High theoretical fuel efficiency: 60% electrical, 85% cogeneration
- Operates at high and constant temperature - heat can be extracted to meet thermal demand

Approach

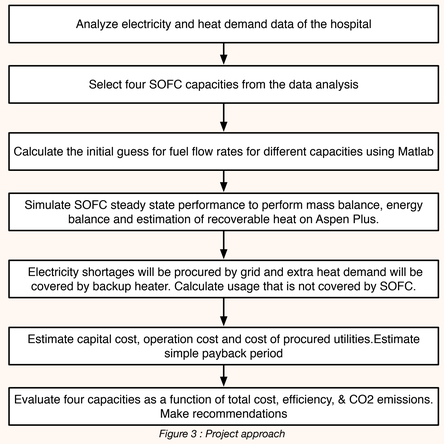
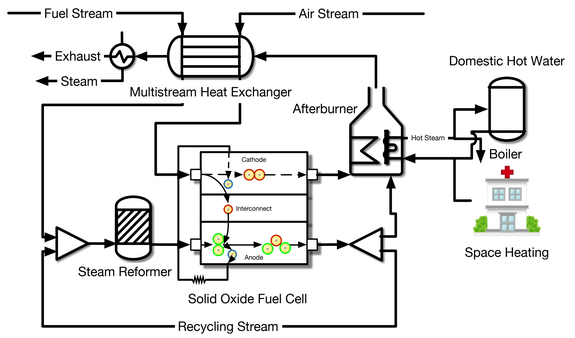


Figure 3 : Project approach

Solid Oxide Fuel Cell



$$Overall: H_2 + \frac{1}{2}O_2 \rightarrow H_2O \quad Cathode: \frac{1}{2}O_2 + 2e^- \rightarrow O^{2-} \quad Anode: H_2 + O^{2-} \rightarrow H_2O + 2e^-$$

SOFC voltage is affected by temperature, anode composition, anode pressure and cathode composition

Steam reformer converts natural gas to hydrogen for SOFC. It produces steam which is then recycled to be used in the reformer.

$$CH_4 + H_2O \rightarrow CO + 3H_2 \qquad C_2H_6 + 2H_2O \rightarrow 2CO + 5H_2 \qquad C_3H_8 + 3H_2O \rightarrow 3CO + 7H_2$$
$$C_4H_{10} + 4H_2O \rightarrow 4CO + 9H_2 \qquad CO + H_2O \rightarrow CO_2 + H_2$$

Modeling Approach

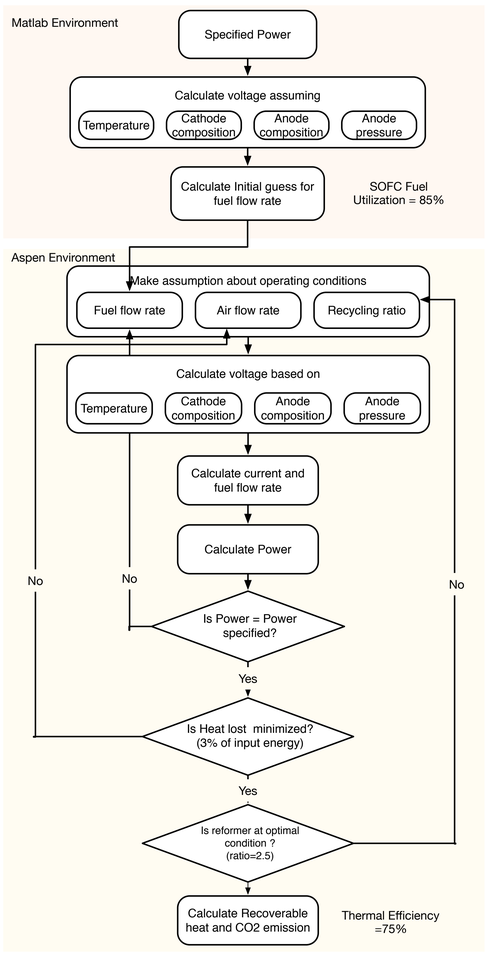


Figure 5: Flow Chart of Simulation Sequence

Simulation Results

Four capacities of SOFC are simulated throughout the project.

For higher capacities of SOFC, higher proportion of electrical demand is satisfied. However, because SOFC runs at constant rate, the proportion of electricity surplus going to waste increases as well.

The higher the capacities of the SOFC, the more heat is recovered from SOFC. Cogeneration is a cost effective way to produce heat than traditional furnace.

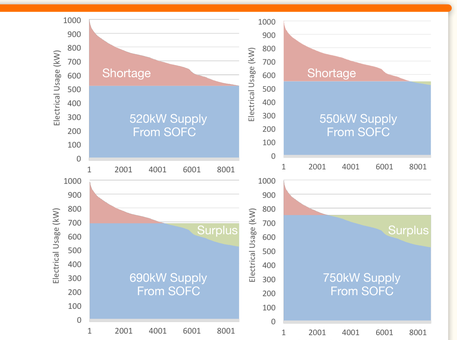


Figure 6: Load Distribution of four SOFC Capacities

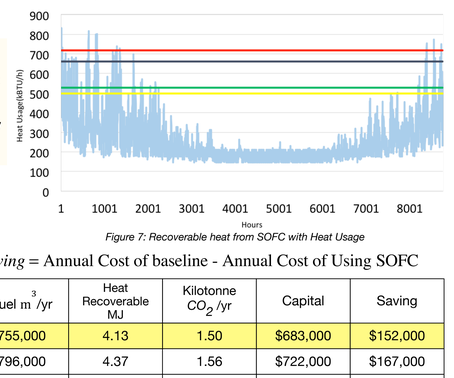


Figure 7: Recoverable heat from SOFC with Heat Usage

$$Saving = \text{Annual Cost of baseline - Annual Cost of Using SOFC}$$

	Fuel m^3/yr	Heat Recoverable MJ	Kilotonne CO_2 /yr	Capital	Saving
520kW	755,000	4.13	1.50	$683,000	$152,000
550kW	796,000	4.37	1.56	$722,000	$167,000
690kW	992,000	5.49	1.89	$906,000	$158,000
750kW	1,075,000	5.96	2.04	$985,000	$30,000
Baseline	104,000	-	0.472	-	-

Table 1 : Comparison of 4 capacities of SOFC with the Baseline

	Efficiency	Cost /kWh	kg CO_2 /kWh
Grid	30~50%	$0.07-$0.12	0.046
SOFC	60% Electrical 16% Thermal	$0.09*	0.308

Table 2 : Comparison of Grid and SOFC **Cost/kWh for 520 kW case*

Economics

Annual Cost

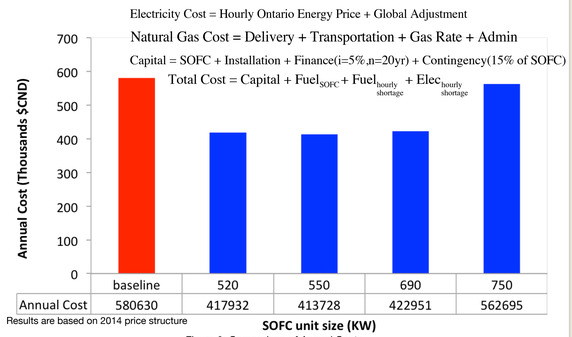


Figure 8: Comparison of Annual Costs

- Electrical shortage is procured. Heat shortage is satisfied by on-demand heater.
- Annual cost decrease because of the cost saving effect of cogeneration. Cost reach a minimum at 550kW and increase as capacity increase because of the surplus in production of electricity

Economics

Simple Payback

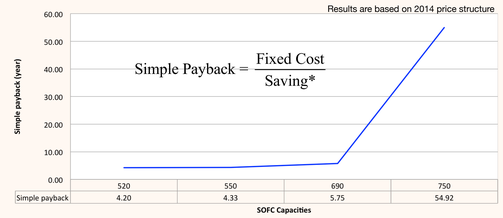


Figure 9: Comparison of Simple Payback Period

- The higher the saving, or the lower the fixed cost, the earlier the hospital experience the cost saving effect. 550kW provide the most saving, but takes longer to payback because of capital cost.

Environmental Assessment

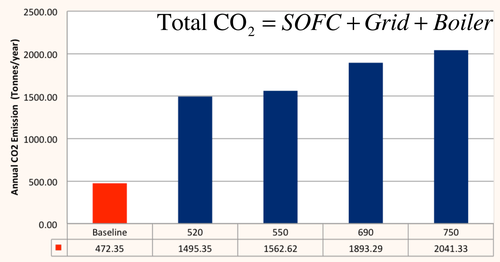


Figure 11: Comparison of Annual CO2 emission using capacities of SOFC and baseline data of the hospital

- Powering SOFC with fossil fuel leads to higher CO2 emission compared to the grid that is highly reliant on nuclear power

Conclusions

- SOFC enables the hospital to save money by generating heat and electricity at the same time. All capacities studies are cheaper than baseline.
- Designing a SOFC with no surplus generation (520KW), the simple payback is the most feasible (4 years and 2 months). Using this SOFC would require the procurement of deficient electricity and fuel for heating during peak hours from the grid.
- Using 520 kW the hospital will save 152,000 CAD annually and the capital cost for this project would be 683,000 CAD. Carbon dioxide emission will be tripled.

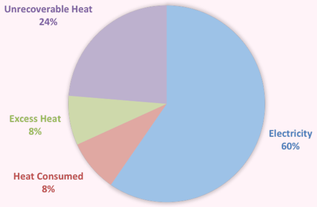


Figure 10: Distribution of Fuel Energy for 520kW SOFC

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