Network design optimization of fuel cell systems and distributed energy devices

LDRD
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

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This work explores financial and economic benefits of novel operating strategies for stationary cogenerative fuel cells.

Problem:

Buildings can consume the same amount of heat and electricity with less fuel and greenhouse gas emissions using stationary fuel cell systems (FCS), but only if these FCS are optimally configured.

	Source of Electricity or Heat	CO_2 Emission Factor (g/kWh_e or g/kWh_heat)	Electricity Production (MWhr)	Heat Production (MWhr)	CO_2 Emissions (kg)
Case 1: Conventional System	Coal Power Plant with Steam Turbine	860	2	0	1720
	Coal Fired Boiler / Furnace	410	0	1	410
	Total		2	1	**2130**
Case 2: Average System	Mix of 1999 US Electric Generation Plant	600	2	0	1200
	Boiler / Furnace (72% efficient)	280	0	1	280
	Total		2	1	**1479**
Case 3: Advanced System	Cogenerative Combined Cycle Gas Turbine	380	2	0.71	760
	Boiler / Furnace (92% efficient)	219	0	0.29	64
	Total		2	1	**824**
Case 4: Fuel Cell System fueled by natural gas	Cogenerative Molten Carbonate Fuel Cell	373	2	1	**746**
Case 5: Fuel Cell System fueled by renewable hydrogen	Cogenerative Molten Carbonate Fuel Cell	0	2	1	**0**

Cogenerative FCS fueled by natural gas can create 1/3rd the carbon dioxide (CO_2) as conventional systems, if they are designed to *recover heat with high in-use capacity utilization.* They generate no CO_2 if fueled by renewable H_2.

Approach:

Model evaluates novel operating strategies for designing, installing, and controlling stationary FCS to provide electricity and heat to buildings

- Examines novel operating strategies
- Optimizes the percentage installation of FCS for
  - minimum CO_2 emissions
  - minimum CO_2 emissions per unit energy cost, or
  - maximum energy cost savings to building owners.
- Optimizes FCS installation for
  - a particular location
  - climatic region
  - array of building load curves
  - FCS type, and
  - competitive environment.
- Shows trade-offs among competing goals:
  - cost savings to building owners, CO_2 reductions, FCS installed capacity, and manufacturer

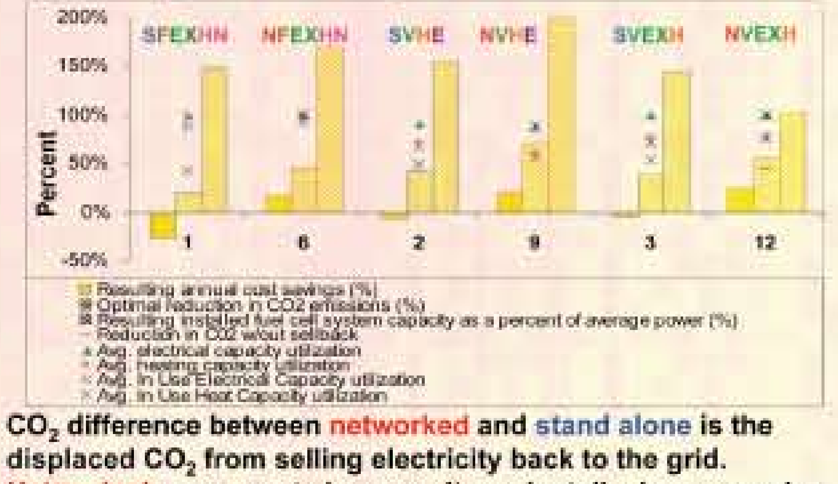
Model investigates 12 novel operating strategies.

			Primary Control	Secondary Control
Strategy	Electrically and Thermally Networked (N) or Stand Alone (S)?	Variable Heat-to-Power Ratio (V) or Fixed Heat-to-Power Ratio (F)?	Electricity Power Load Following (E), Heat Load Following (H), or No Load Following (EX)?	Electricity Power Load Following (E), Heat Load Following (H), or No Load Following (HN, HX, EN, EX)?
1	S	F	EX	HN
2	S	V	H	E
3	S	V	EX	H
4	N	F	E	HN
5	N	F	E	HX
6	N	F	EX	HN
7	N	F	EX	HX
8	N	V	H	EN
9	N	V	H	E
10	N	V	E	H
11	N	V	H	EX
12	N	V	EX	H

Most FCS are now installed as Strategy 1 [SFEXHN]

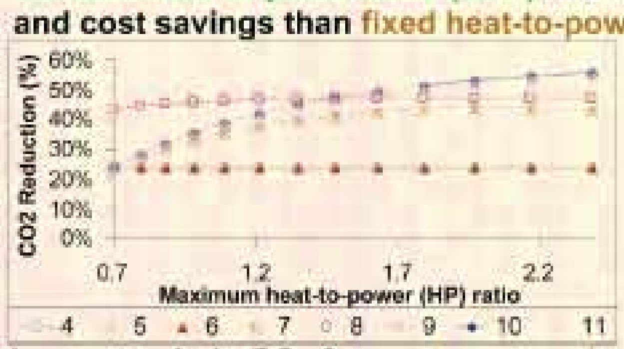
Results:

For the same configuration, networked (red outline) has higher CO_2 & cost savings than stand alone (blue outline)

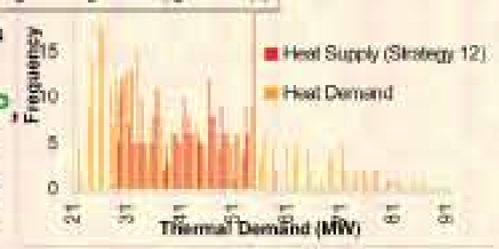


CO_2 difference between networked and stand alone is the displaced CO_2 from selling electricity back to the grid. Networked saves costs because it can install a larger number of systems while maintaining a high FCS capacity factor.

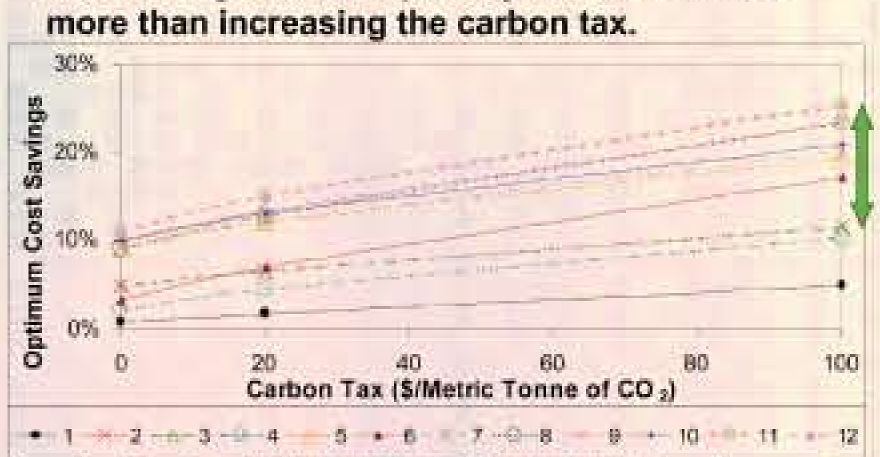
Variable heat-to-power ratio (VHP) has higher CO_2 and cost savings than fixed heat-to-power ratio



Largest gain in CO_2 & cost savings with initial increase in VHP, as VHP supplies to a larger portion of heat demand distribution.



Changing to novel strategies can increase energy cost savings and the quantity of FCS installed more than increasing the carbon tax.



Novel strategies (11 [NVHEX] & 12 [NVEXH]) show the most cost savings. Combining a carbon tax with novel strategies augments tax's impact on cost savings & installed capacity.

Significance:

1. Model highlights the most valuable areas for fuel cell R&D and the best stationary FCS operating strategies.
2. Different strategies achieve diverse goals of cost savings to building owners, high fuel cell manufacturer sales, CO_2 emission reductions, and high CO_2 savings per unit cost.
3. The environment sees the highest CO_2 reductions and building owners get the highest energy cost savings by switching to novel strategies:
   1. Switch from stand alone (S) to networked (N), then
   2. Switch from fixed (F) heat-to-power ratio to variable (V).
   3. When already NV, load following has little impact, assuming constant energy prices over time.
4. Model advances stationary cogenerative FCS designs, which could save the U.S. 1/5th of its energy consumption (21 Quads -- the heat lost at power plants and later re-generated at buildings) and an even larger proportion of U.S. greenhouse gas emissions.

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