Unraveling the Paradox: The Economics of Using Otherwise Wasted Heat for Chilling

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Motivation

• Air conditioning in commercial buildings accounts for 16% of California’s electricity consumption
  • Estimated to grow at 1.30% p.a. through 2024

• Dominant technology: Electric Chillers, which contribute to peak electricity consumption

• A high-temperature fuel cell (“HTFC”) generates significant amounts of high quality exhaust heat

• Exhaust heat is wasted in electricity-only fuel cell operations

• If captured, otherwise-wasted exhaust heat can be fed to an absorption chiller for air conditioning.
Piping & Instrumentation Diagram
Absorption Chiller: How It Works
HTFC/Chiller Model: Major Components

1. User Interface to specify building type and select equipment

2. Equipment dispatch to meet building load

3. Levelized Cost of Energy ("LCOE") calculations based on equipment dispatch
HTFC/Chiller Model: User-Friendly Interface
HTFC/Chiller Model: Cost Module Flowchart

1. Initialize Building Loads (Electric, Cooling, Heating)
2. Identify each piece of equipment to be included in portfolio
3. Calculate capacity, load factor, capex and opex per MWh or MWh_{eq}
4. Calculate WACC, depreciation, taxes, loan interest & principle pmts
5. Increment/decrement equipment MWh or MWh_{eq} generated or used

Financial inputs
- Technology-specific costs (capital, O&M)
- Taxes & depreciation rates
- Natural gas price forecast
- Electricity prices (forecast or from rates module)
- All other cost-related inputs

Annual MWh electricity generated
Annual ton-hours chilling generated
Annual MMBtu heating generated
Fuel input (natural gas or electric) required per MWh
CO2 emissions per MWh or MWh_{eq} of output
Other operating inputs from technical module

Run total revenue loop as initialized or as incremented/decremented
Calculate NPV of annual revenue, taxes, after-tax net income
Calculate WACC, depreciation, taxes, loan interest & principle pmts
Increment/decrement equipment MWh or MWh_{eq} generated or used

Is there another piece of equipment to be included?
Yes
Calculate equipment NPV of annual cost of energy in MWh or MWh_{eq}
Calculate system (portfolio) LCOE using NPV of each piece of equipment’s annual COE and annual MWh or MWh_{eq}

No
Does pre-tax income cover required equity return?
Yes
Initialize NPV of required equity return

R1 (15 OCT 2013)
LCOE Changes with Size & Building Load

• Optimal fuel cell size depends on availability of complementary technologies
  • Higher capacity, lower capacity factor
  • Lower capacity factor, higher LCOE

• Thermal energy storage (“TES”) and/or natural gas-fired boiler allow for smaller HTFC capacity and greater efficiencies
  • Must balance efficiencies vs. equipment costs

• Model an existing building on UCI campus
  • Multipurpose Science & Technology Building (“MSTB”)

• All physical flows converted to MW or MWh electric or thermal, as appropriate
MSTB: Traditional Cooling/Heating

Comparison of LCOE Components by Gen Tech

Levelized COE, $/MWh

Fuel
Transmission
VOM
CO2 Tax
FOM
INS
Net Equity
Debt
ADV
State Tax
Federal Tax

Total (left)
Non-Renewable (center)
Renewable (right)

Portfolio LCOE = $120.5437/MWh
Portfolio CO2 = 6509.3304 tons
MSTB: 300 kW FC + Abs Chiller + Boiler

Comparison of LCOE Components by Gen Tech

- Fuel
- Transmission
- VOM
- CO2 Tax
- FOM
- INS
- Net Equity
- Debt
- ADV
- State Tax
- Federal Tax

Portfolio LCOE = $119.8008/MWh
Portfolio CO2 = 17387.0093 tons
MSTB: Add Electric Chiller for Backup

Comparison of LCOE Components by Gen Tech

- Fuel
- Transmission
- VOM
- CO2 Tax
- FOM
- INS
- Net Equity
- Debt
- ADV
- State Tax
- Federal Tax

Levelized COE, $/MWh

Gen Tech ID

Portfolio LCOE = $129.3036/MWh
Portfolio CO2 = 17429.8047 tons
MSTB: TES Instead of Electric Chiller

Comparison of LCOE Components by Gen Tech

Levelized COE, $/MWh

- Fuel
- Transmission
- VOM
- CO2 Tax
- FOM
- INS
- Net Equity
- Debt
- ADV
- State Tax
- Federal Tax

Total (left)
Non-Renewable (center)
Renewable (right)

Portfolio LCOE = $126,243/MWh
Portfolio CO2 = 173,877.0093 tons
Conclusions

- A high-temperature fuel cell/absorption chiller unit effectively displaces traditional electric chillers
- Peak and total electricity consumption is reduced
  - Value of peak reduction is not monetized
- LCOE is reduced vs. the traditional technology
  - $119.80/MWh vs. $120.54/MWh
- Backup equipment increases LCOE & reliability
  - Value of increased reliability is not monetized
- Adding complementary technologies increases fuel cell sizing flexibility and operating efficiencies
- Ongoing research
  - What is the potential market size in California?
  - What are the market entry barriers?
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