Cogeneration Systems for Powering and Cooling Data Centers

The Green Data Center at Syracuse University

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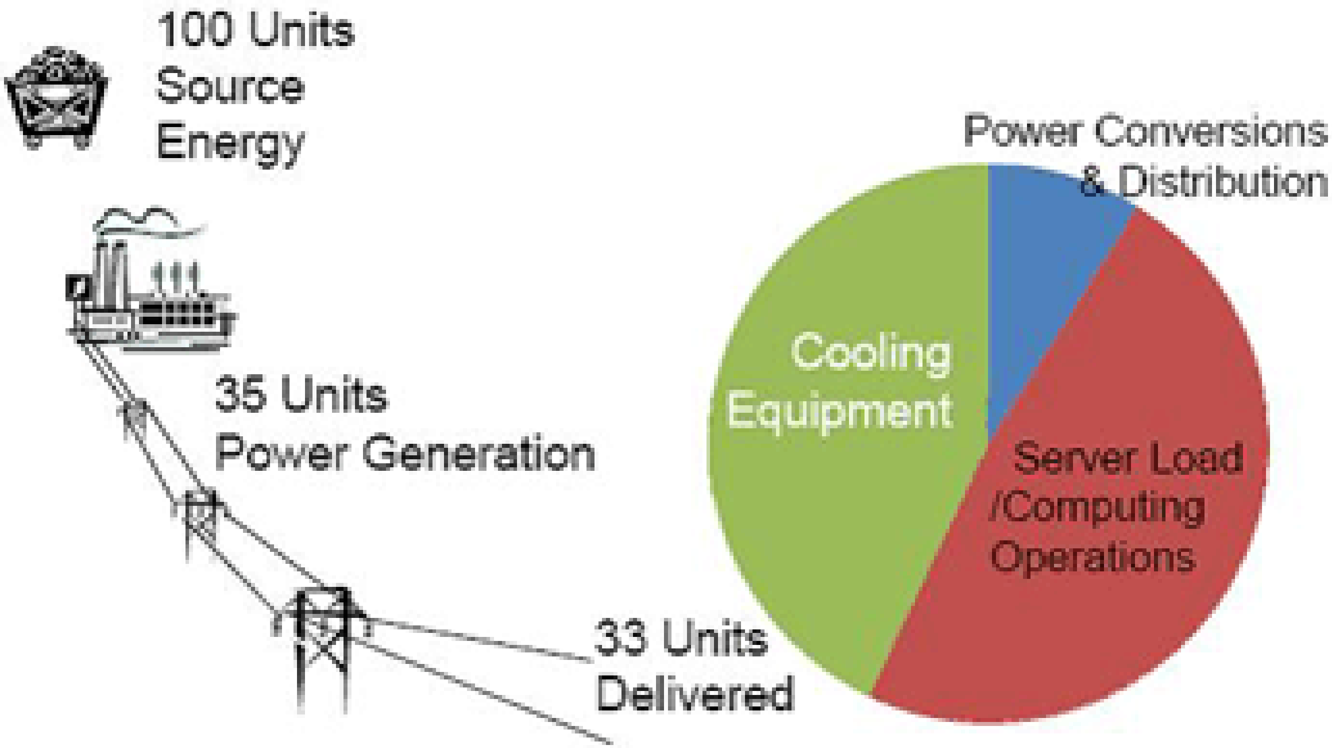
Outline

- Why CoGen for Data Centers?
- CoGen System Configuration
- Multi-City Assessment of CoGen for Data Centers
- Case Study – Data Center for a Healthcare Complex
- SU’s Green Data Center
- New Metrics for CoGen Data Centers
- SU’s Green Data Center Performance

Data Center Power Supply Chain

Opportunity for efficiency improvement with on-site cogeneration…

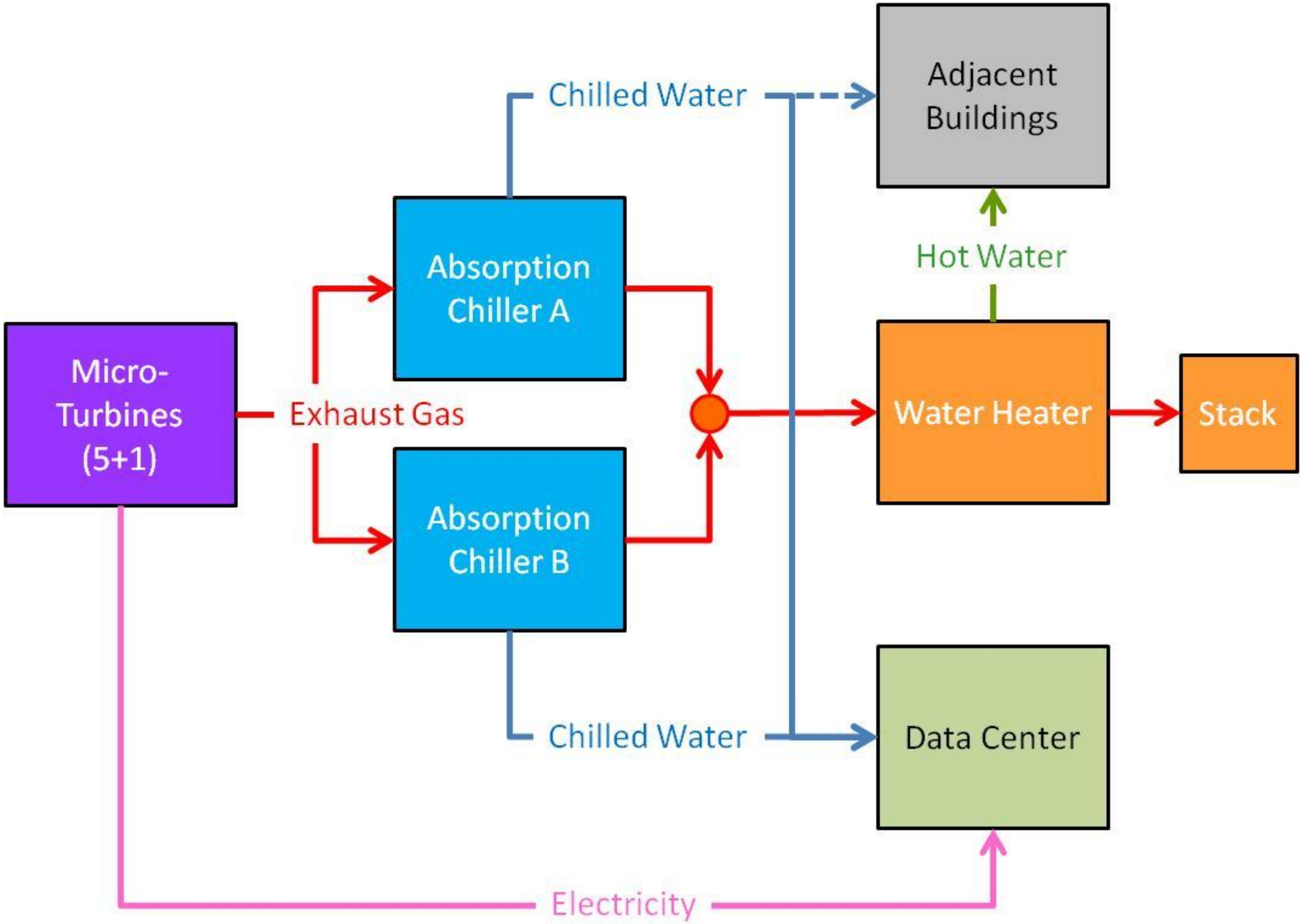


US DOE Industrial Technologies Program

Why Cogeneration for Data Centers?

- With on-site power generation, the waste heat from the power system can be used to cool the data center, and cool/heat adjacent buildings.
- Because the electric and thermal demands of data centers are strongly correlated, the utilization of the cogeneration system’s energy outputs can be much higher.
- On-site power generation can provide DC power to the data center, where almost all computer loads are DC. This reduces wasteful multiple conversions of AC/DC.
- Redundancy and uninterruptible power supply are potentially less expensive to provide in a data center powered and cooled by a cogeneration system.

Typical Cogeneration System Block Diagram



Cogeneration Modes

nAB = no Adjacent Blg; SAB = Small Adjacent Blg; LAB = Large Adjacent Blg.
With and without Data Center Economizers.

- Cooling Matching (CM/nAB)
  - *Cogeneration system size based on data center cooling demand.*
  - *Not sufficient to supply all electricity demand.*
  - *Grid supplies additional electricity (grid-dependent)..*
  - *Waste heat used only for cooling data center.*

- Cooling Matching (CM/SAB; CM/LAB)
  - *Cogeneration system size based on data center cooling demand.*
  - *Grid supplies additional electricity (grid-dependent).*
  - *Excess cooling and heating exported to adjacent building.*

- Power Matching (PM/SAB; PM/LAB)
  - *Cogeneration system size based on data center electricity demand.*
  - *Excess cooling and heating exported to adjacent building.*

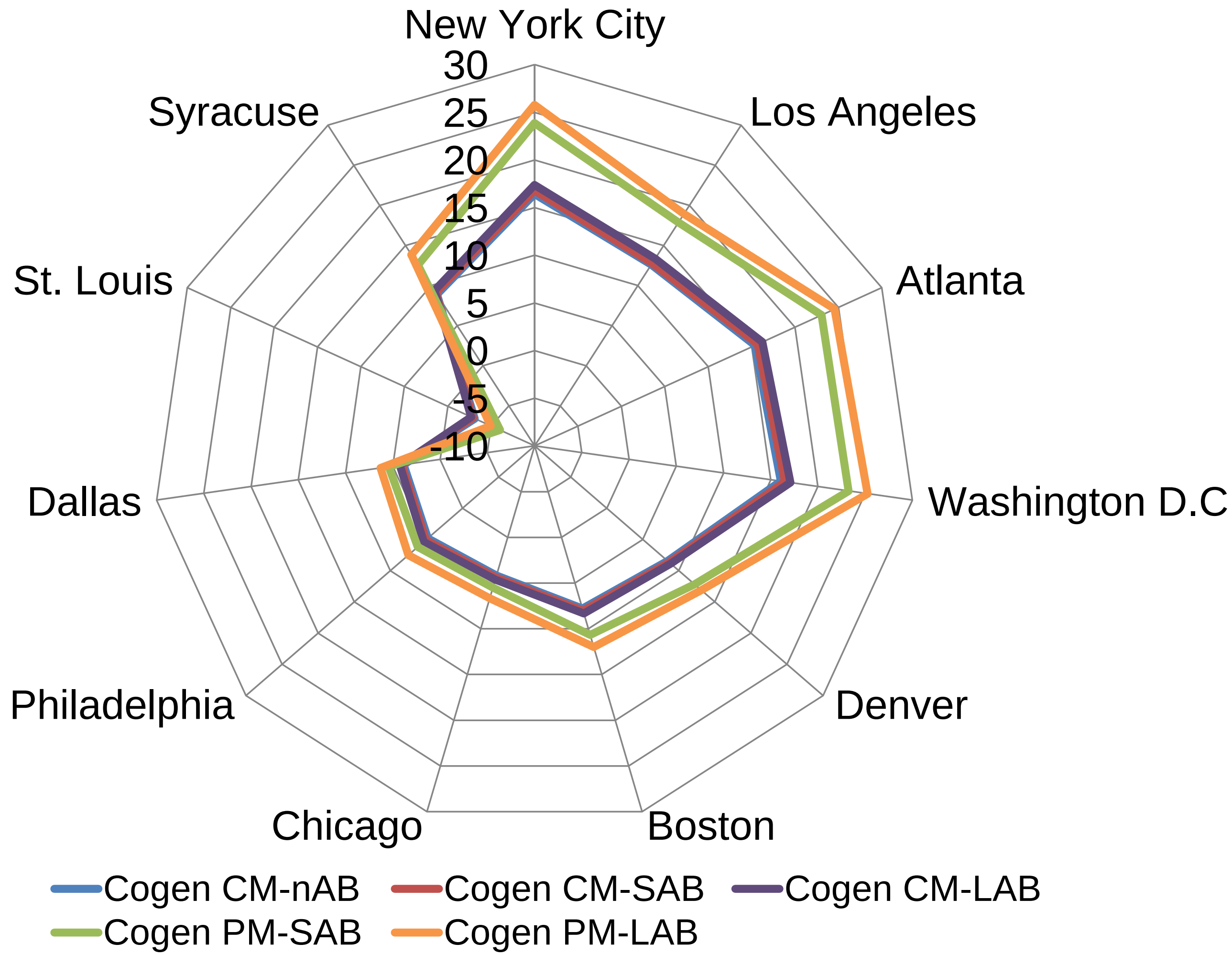
Baseline: Typical Conventional Data Center

Hour-by-hour analysis to account for weather and part-load performance of system components …

- Baseline Data Center Specifications
  - *1 MW IT Load*
  - *15°C temperature rise across servers*
  - *Open-aisle / No Economizer*
  - *7°C Chilled Water Supply Temperature*
  - *14°C CRAH Supply Air Temperature*
  - *90% Tile-to-Rack Flow Rate Ratio*
  - *25% Floor Leakage*
  - *PUE ≈ 2.0*

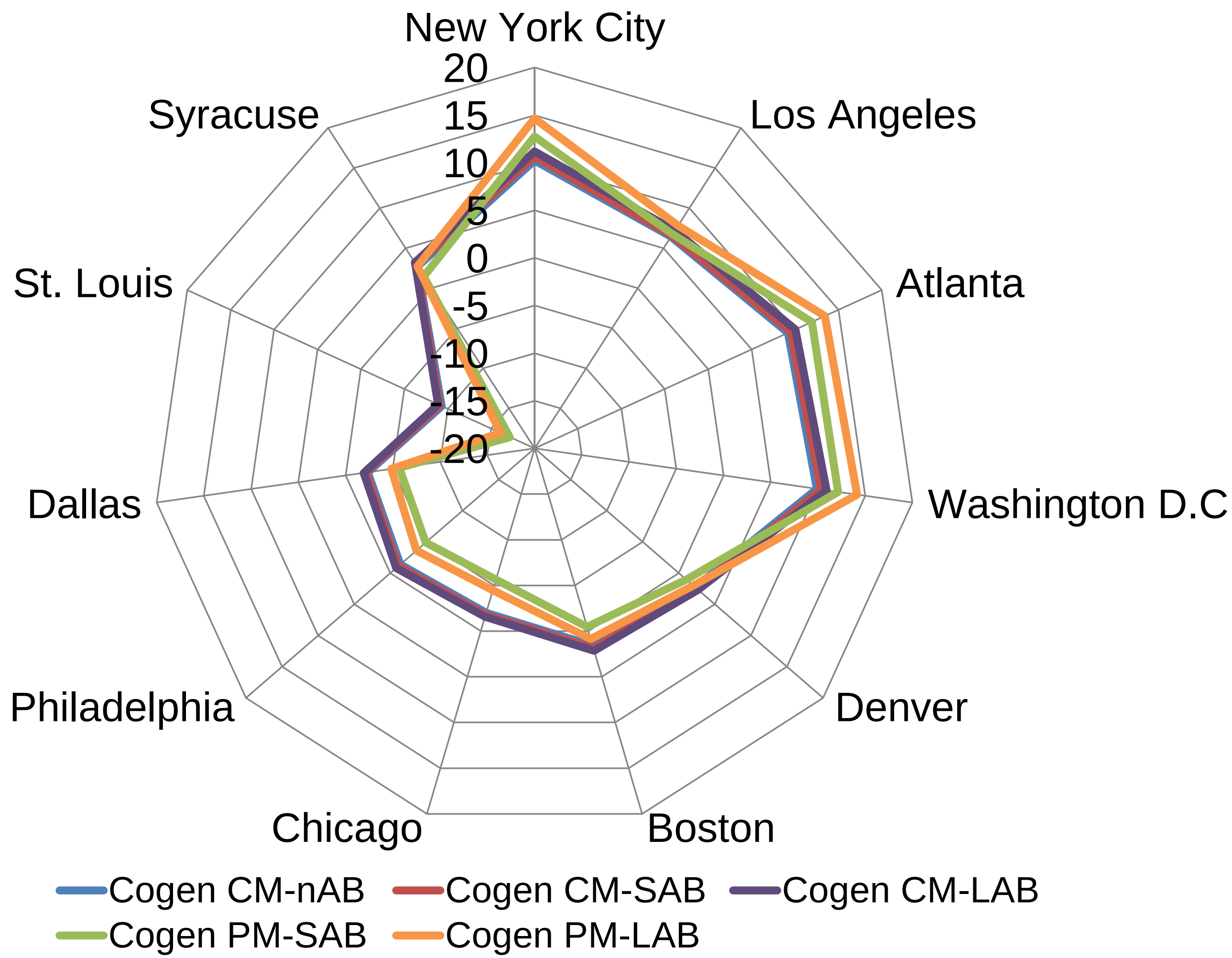
Present Value of Energy Cost Savings ($M)

Present Value computed over 20 years for 5% Discount Rate – 1 MW IT Load



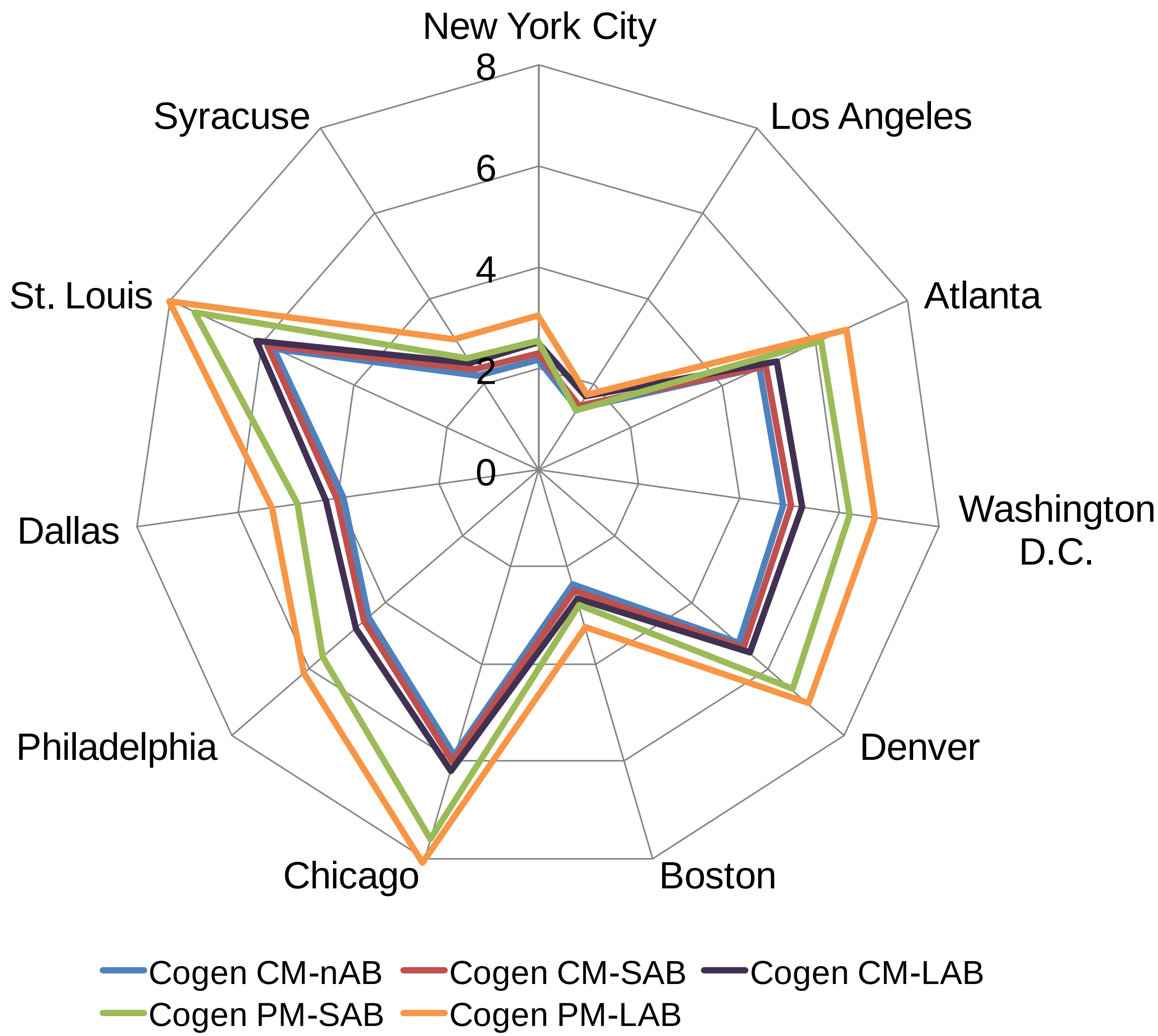
NPV Comparison ($M)

Incremental NPV of Energy Savings and Equipment Capital + O&M Costs



CO_2 Emissions Reduction (10^3 Metric Ton/Year)

Comparison of Fossil-Fuel-Fired Power Plants vs. On-Site Cogen System



Case Study – Data Center for a Healthcare Complex

Conventional and Cogeneration Data Center Infrastructures…

- Location: Northern PA
- Proposed Data Center:
  - *200 kW IT (approximately 300 kW total) initial capability*
  - *Tier-3 reliability*
- Comparison of capital and operating costs of Conventional and Cogeneration (CoGen) data center infrastructures.

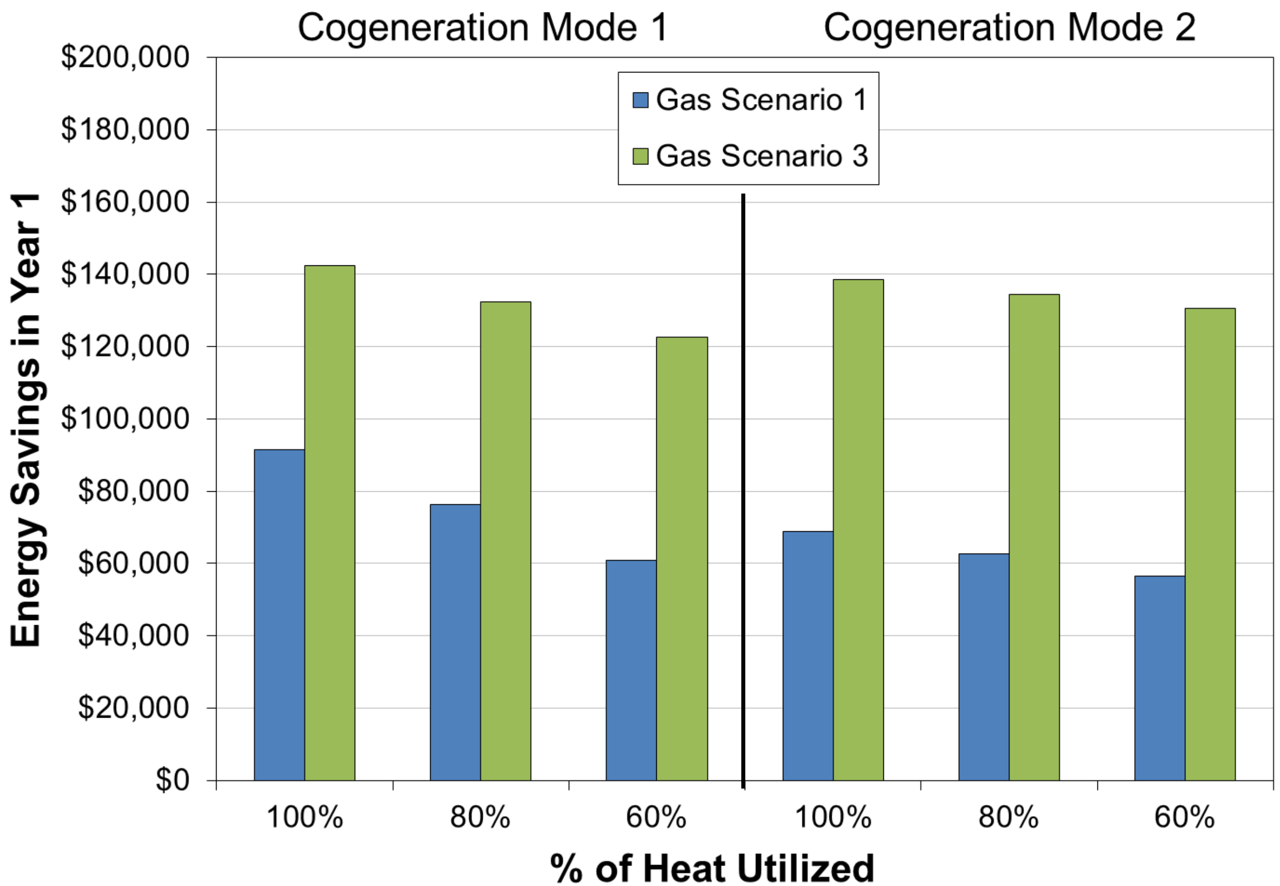
Energy Price Scenarios

Real annual escalation rate: Gas = 1.3%; Electricity = 0.3% (DoE/PA).
We focus on Scenario 3 in this presentation…

	Gas Price Scenario		
	Scenario 1	Scenario 2	Scenario 3
Electricity $/kWh	0.08	0.08	0.08
Natural Gas $/Therm	0.68	0.58	0.44
Gas/Electricity Cost Ratio	0.29	0.25	0.19

Annual Energy Savings

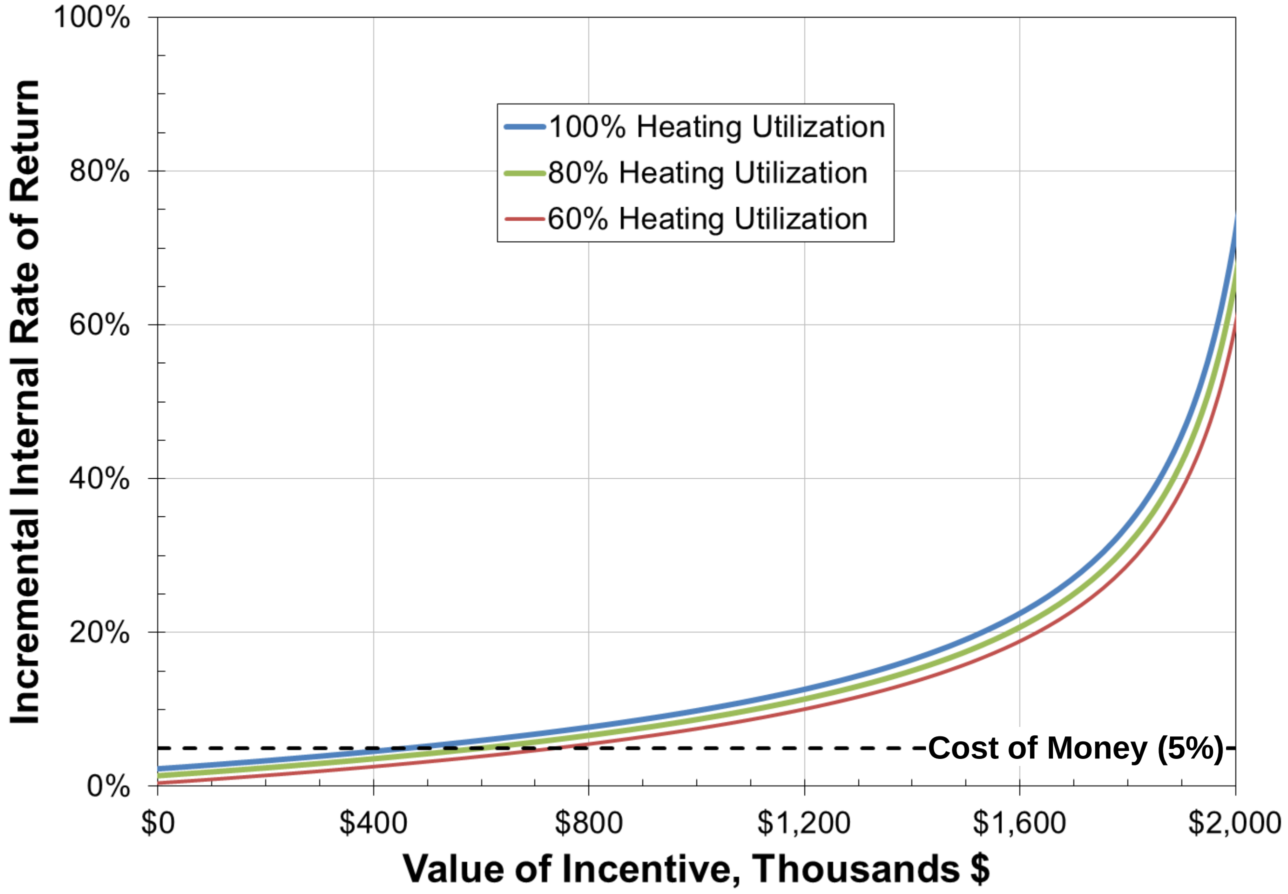
The CoGen system offers substantial energy cost savings relative to competing conventional system…



Conventional system: screw chillers (rated COP ~ 4.7) and gas-fired furnace (rated efficiency ~ 84%).

Incremental IRR (Gas Price Scenario 3)

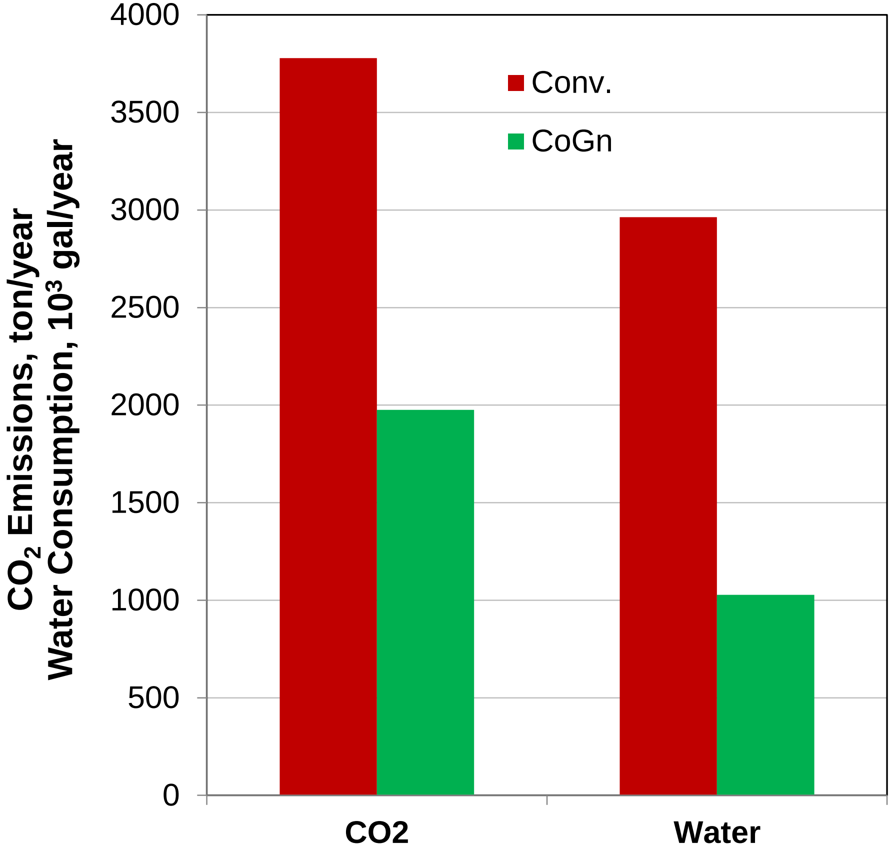
Government incentives are available in many states to offset the high cost of current limited production cogeneration systems…



Environmental Benefits

The Cogeneration system offers substantial reductions in CO_2 emissions and water use relative to conventional infrastructure

- **CO_2 Emissions**:
  - *Cogeneration system uses natural gas fired microturbines with a CO_2 emission factor of 1.52 lb/kWh (Capstone)*
  - *Conventional system is based on the ability of the cogeneration system to offset the electricity generation of fossil-fuel power plants and the gas used by the on-site boilers (84% efficiency)*
  - *Generation mix in PA: 39% coal + 20% natural gas.*
- **Water Use**:
  - *Conventional system[1] requires make-up water in the on-site cooling towers and additional water to generate the electricity at the remote power plant.*
  - *Cogeneration system only requires water in the on-site cooling towers.*



1. *Assuming an 85% electrical distribution efficiency, Pennsylvania electricity generation mix, and power plant water use estimates from EPRI (2008)*

The SU/IBM Green Data Center

- Powered and cooled by an on-site CCHP system:
  - *12 Capstone C65 micro-turbines*
  - *2 waste-heat activated double-effect absorption chillers*
  - *Dual mode AC/DC power supply*
  - *Grid connected or grid independent operation*
  - *Battery backup (no conventional UPS)*
  - *Propane fuel emergency backup*
- Extensive use of water cooled racks
- Surplus cooling/heating/power is used by adjacent office building
- Goal: 50% reduction in primary energy use.

Capstone C65 Microturbines

Two banks of 6 turbines each provide N+1 reliability and generate a net 600 kW of electrical power.

Thermax Absorption Chillers

2 double-effect absorption chillers convert the 585 F exhaust into chilled water (~300 tons of cooling).

Waste Heat Exchangers

These heat exchangers provide domestic hot water and space heating to an adjacent campus building.

Water Cooling at the Rack

Each of the equipment racks is water cooled. Rear-door HX removes >10kW; Sidecar HX removes ~30 kW.

Battery Backup

40 tons of sealed flooded wet cell batteries provide 20 minutes of runtime at full power.

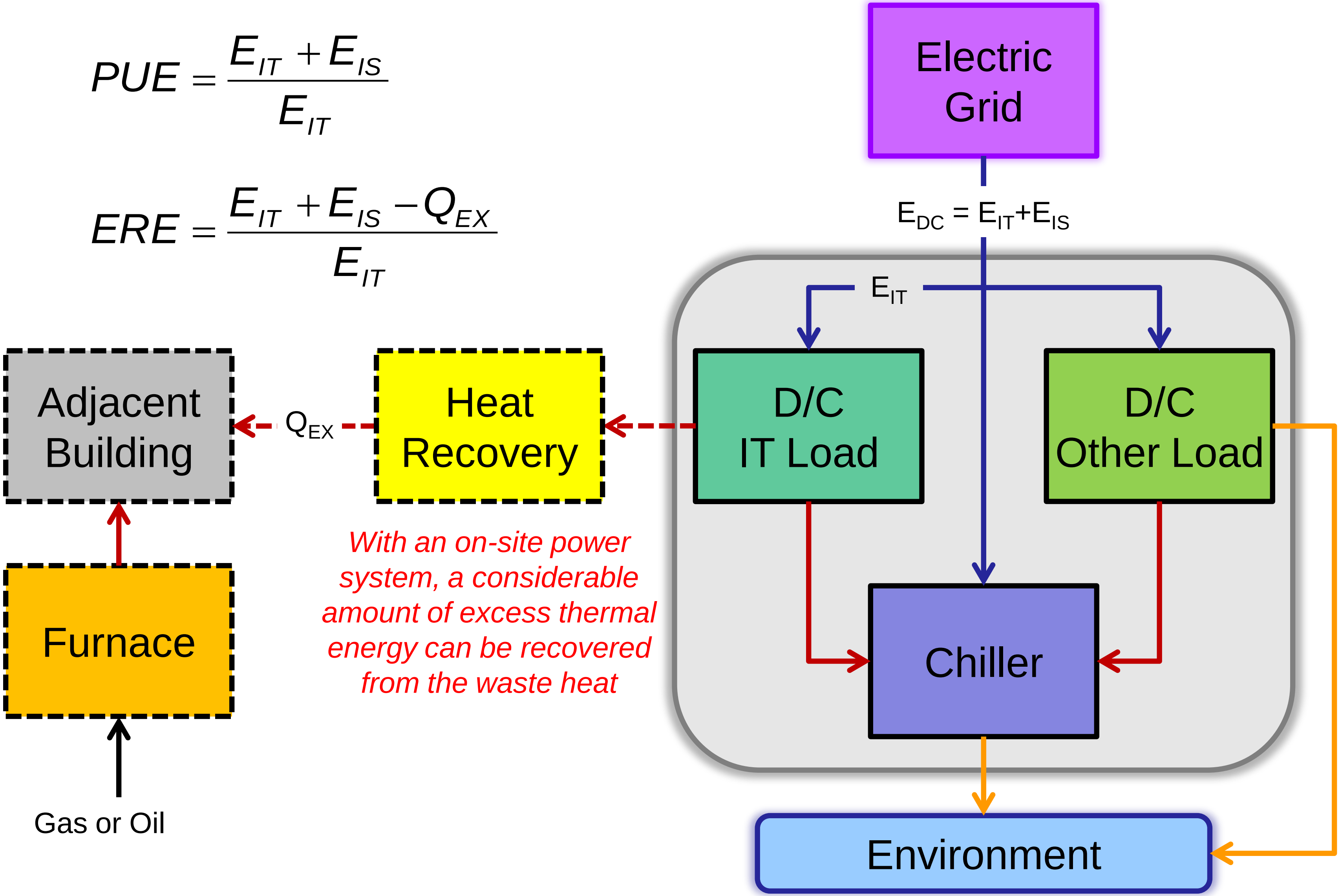
IBM DS8300, Z10, and P575

The IBM Z10 Mainframe shown here (2^{nd} and 3^{rd} racks) is running on DC power.

Typical Data Center Energy Flow Block Diagram

$$PUE = \frac{E_{IT} + E_{IS}}{E_{IT}}$$

$$ERE = \frac{E_{IT} + E_{IS} - Q_{EX}}{E_{IT}}$$



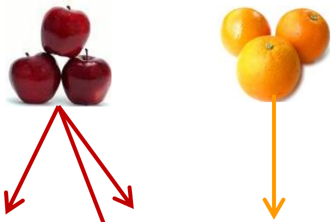
The Green Grid ERE Metric

If there is a nearby user of the data center waste heat…

- In PUE, all energy flows are expressed in terms of electricity:

$$\mathrm{PUE} = \frac{E_{IT} + E_{IS}}{E_{IT}}$$

- In ERE as defined by TGG, we subtract heat from electricity!!!



$$\mathrm{ERE} = \frac{E_{IT} + E_{IS} - Q_{EX}}{E_{IT}}$$

Heat is not Equivalent to Electricity

A rational ERE metric must recognize difference between heat and electricity…

- Heat and electricity are not thermodynamically equivalent:
  - *Electricity is energy of the highest thermodynamic quality. It is "exergy"…*
  - *The thermodynamic quality of heat depends on the temperature at which it is available. The higher the temperature, the higher the quality – "exergy"*
- Nor is heat economically equivalent to electricity:
  - *The adjacent building that would use the energy exported by the data center (Q_{EX}) will use this energy to displace heat derived from a fuel-fired furnace or boiler, not from an electric heater.*
  - *A certain amount of energy derived from a fuel (gas or oil) is typically much less expensive than the same amount of electricity (kJ for kJ).*

How to Fix TGG's EER Problem

We need a rational, yet simple approach that recognizes the fact that heat and electricity do not have the same worth…

- Introduce a simple Heat-to-Electricity Equivalence Ratio, C_r:

$$ERE' = 1 + \frac{E_{IS} - C_r Q_{EX}}{E_{IT}}$$

- There are three ways to obtain a reasonable estimate of C_r:
  1. *A rigorous thermodynamic estimate based on exergy;*
  2. *A practical thermodynamic estimate based on realizable fuel-to-electricity conversion efficiency;*
  3. *An economic estimate based on the relative price of fuel and electricity.*

The Economic Equivalence Approach

Based on the ratio of fuel cost to electricity cost…

- Part of the waste heat from the data center, Q_{HB}, will displace heat that would have been supplied by a gas-fired furnace with an efficiency η_f ; *typically* $\eta_f \approx 0.85$.
- Part of the waste heat from the data center, Q_{CB}, will displace cooling that would have been supplied by an electricity-driven chiller
- The ERE definition becomes:

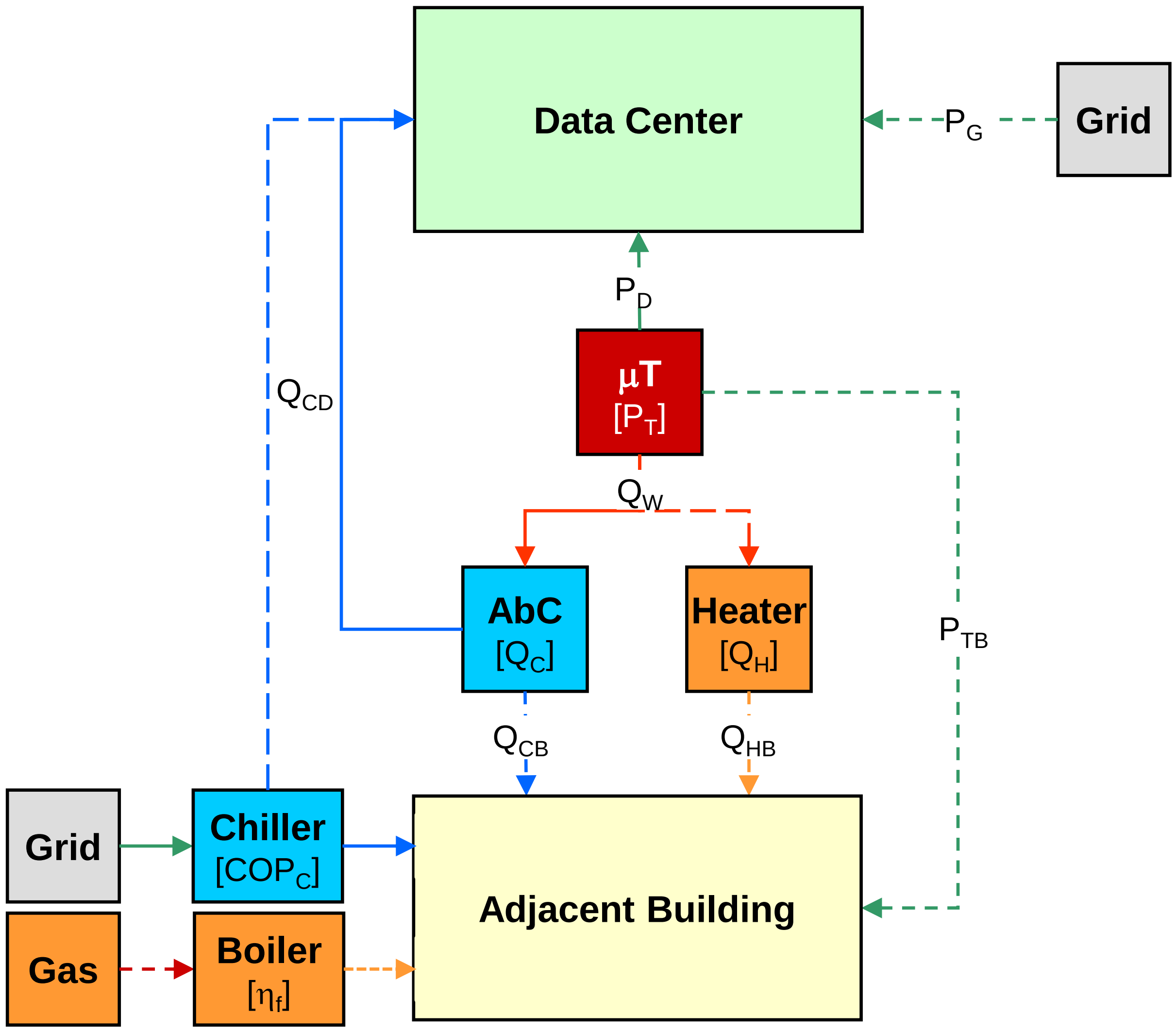
$$ERE_1 = 1 + \frac{E_{IS} - Q_{CB}/COP_C - \left(c_g / c_e\right) Q_{HB}/\eta_f}{E_{IT}}$$

where c_g and c_e are the gas and electricity prices in $/MJ. Therefore,

$$C_r = (c_g/c_e)/\eta_f$$

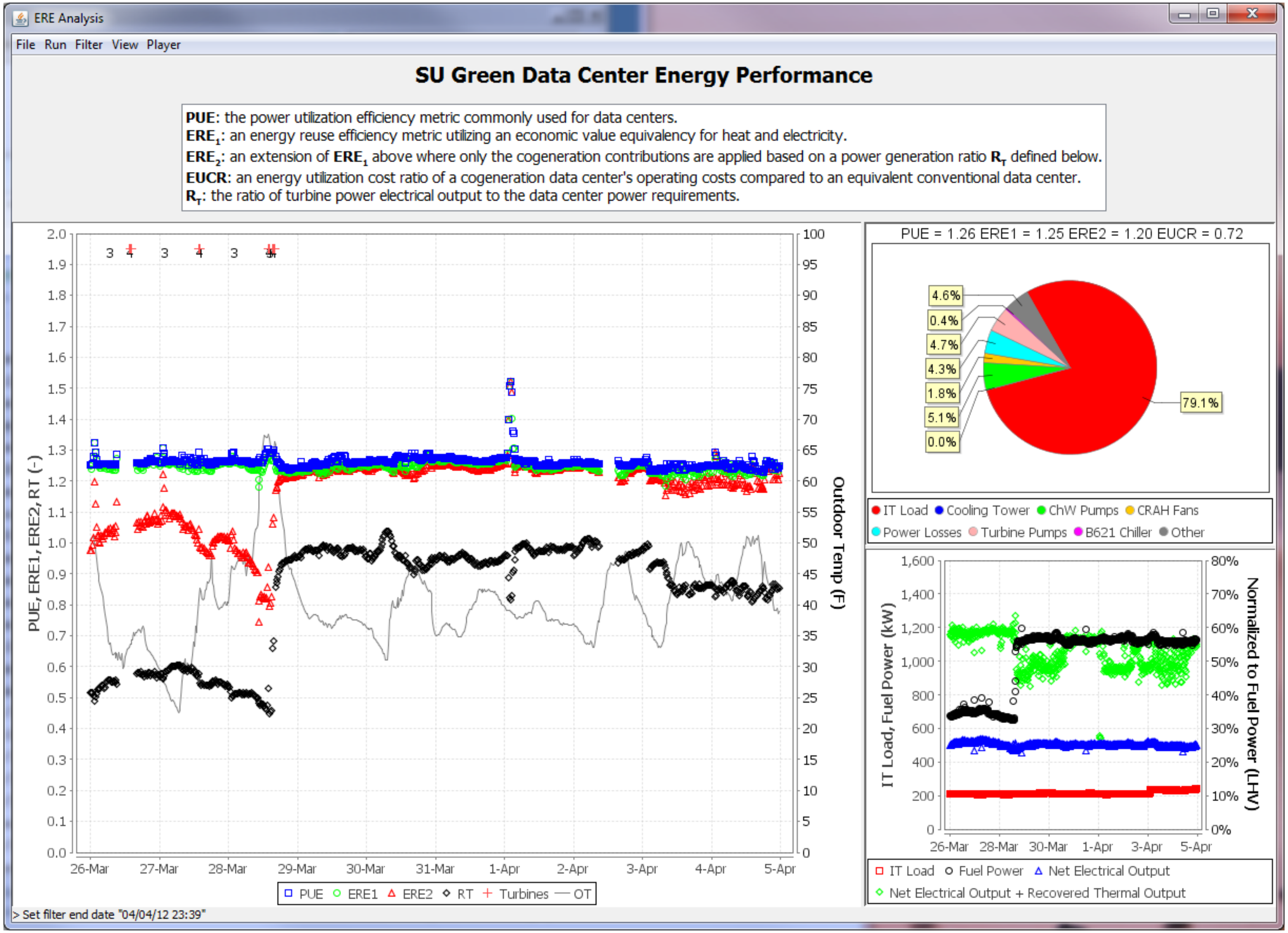
- The commercial gas/electricity price ratio in the US is typically *0.2-0.4*, therefore a value of $\boldsymbol{C_r \approx 0.35}$ is a reasonable average value.

Multiple Operating Modes at SU GDC



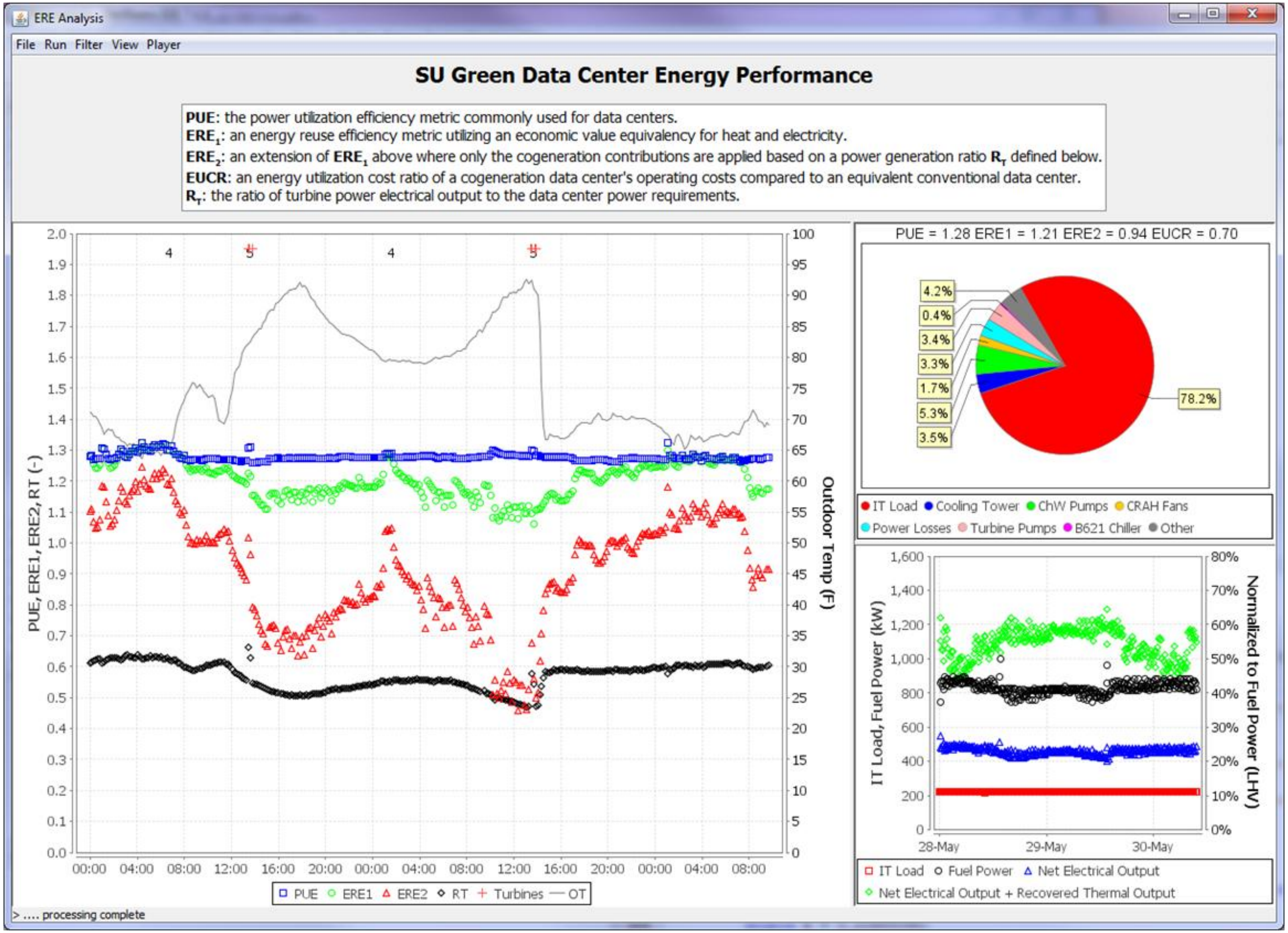
Performance Analysis (Spring 2012)

3/26/12 @ 1am until 4/4/12 @ 11pm…



Performance Analysis (Spring 2012)

5/28/12 @ 1am until 5/30/12 @ 11am…



Questions?