T. B. Simon Power Plant

Combined Heat and Power
Heat Rate and Future Emissions

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The mission:

The mission of the T. B. Simon Power Plant is to provide a reliable, cost efficient energy source to MSU while exceeding expectations for environmental quality. The pursuit for excellence in service and optimal efficiency are the foundation for the plant's initiatives.

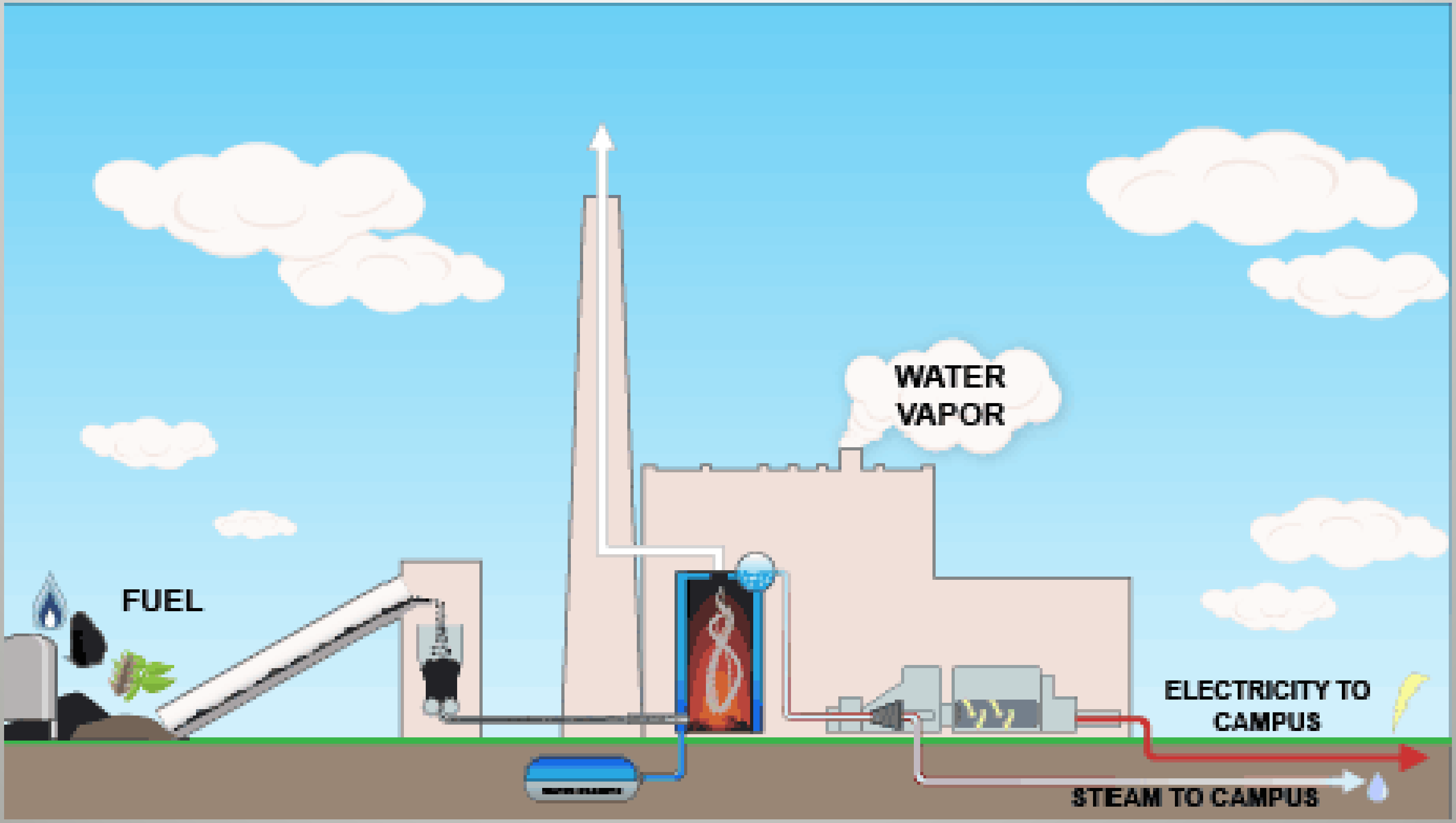
The University is taking bold steps to conserve energy on the demand side. The Simon plant is doing the same on the supply side. Along this path we must optimize the plant while considering the following:

- Seasonal temperature variation
- Office and academic electric load
- Campus events
- Fuel type and quality (biofuel / NG / coal)
- On campus residential occupancy
- Summer cooling load
- Grid tie-line purchases
- Campus infrastructure choices (existing and planned)
- Reliability (Remember August 2003?)

What is CHP?

- **C**ombined **H**eat and **P**ower
- Wikipedia.org defines CHP as the use of a power station to simultaneously generate electricity and useful heat.
- By combining what are typically separate processes of generating electricity and heat, efficiency can be higher.

Simon plant CHP Process



http://ipf.msu.edu/green/energy/generating-power.html

Why might CHP be a good choice?

- Efficient: overall can be a better use of fuel if you have something useful to do with the heat (steam in most cases).
- Emissions: more efficient means smaller environmental impact for the same benefit.
- Life safety: having the energy conversion process (combustion) in a central location reduces the need for individual heat sources in buildings or processes.

Life Safety?

Burning MAC Shops and Engineering Building, March 5, 1916. (Shops were also called "the Mechanical Laboratory.")

Photo from the 1955 MAC yearbook, *The Wolverine*, page 69. *Courtesy of Michigan State University Archives and Historical Collections*

http://www.egr.msu.edu/about/history-college

Efficiency and heat rate

- Efficiency is defined by output energy divided by input energy. This gives you a unit-less value such as percent. It is best applied to CHP and processes that use the generated thermal energy.

0.60 or 60%

- Heat rate is another way to define efficiency, it relates how much input energy (fuel) is required to get a unit of output energy. That means a lower number is better. It has units. If it was a car, think of it as gallons per mile.

5687 BTU/ KWH

Early morning story problem quiz…

(Remember there is 1 CE credit available if you attend both days and complete your CIBO survey)

- In all of January 2014, MSU's Simon CHP plant produced 336.2 million pounds of 90 lb. pressure steam at 385F for campus heating and 22,550 MWH of electricity.
- To do this, the plant consumed 8,644 tons of coal, 464,184 MCF of natural gas, and 470 tons of biofuel.
- On your napkin, using the concepts presented, please calculate the percent efficiency.
- Eyes on your own napkin, please.

Output first:

- 336,200,000 lbs of steam x 1095.73 BTU/lb. = 368,433 million BTU
- 22,550 MWH x 3,412,142 BTU / MWH for electricity = 76,951 million BTU
- Now for Input

Input:

- 8,644 tons x 2,000 lbs/ton x 12,000 BTU/lb. for coal = 207,456 million BTU
- 464,184 MCF x 1,012,000 BTU / MCF for natural gas = 469,754 million BTU
- 470 tons x 2,000 lbs/ton x 5,000 BTU/lb. for biofuel = 4,700 million BTU

Remember it's output over input

- Dropping the millions

$$\eta_{th} = \frac{(BTUs_{team} + BTUe_{lectric})}{(BTU_{coal} + BTUg_{as} + BTUb_{io})}$$

$$\eta_{th} = \frac{(368{,}433 + 76{,}951)}{(207{,}456 + 469{,}754 + 4{,}700)}$$

$$\eta_{th} = 0.653\text{, or } 65.3\%$$

So that means MSU gets 65 cents worth of value for each dollar spent on fuel

Heat Rate

- Heat rate typically applies to electrical only utility generation, it’s units of BTU/KWH are useful. It can be applied to thermal processes since KWH represents a unit of energy.

Now in BTU / KWH

- Perfect efficiency is 3,412 BTU / KWH, this is the thermal value of a KWH of electricity.

- To get the total thermal heat rate of the Simon Plant for January we take

$$HR_{thermal} = \frac{3{,}412\ BTU/KWH}{\eta\ _{th}} = \frac{3{,}412}{0.653} = 5{,}225\ \text{BTU/KWH}$$

- So that means MSU puts 5,225 BTU into each kilowatt for an hour of useful output.

2012 EIA US Average Heat Rates

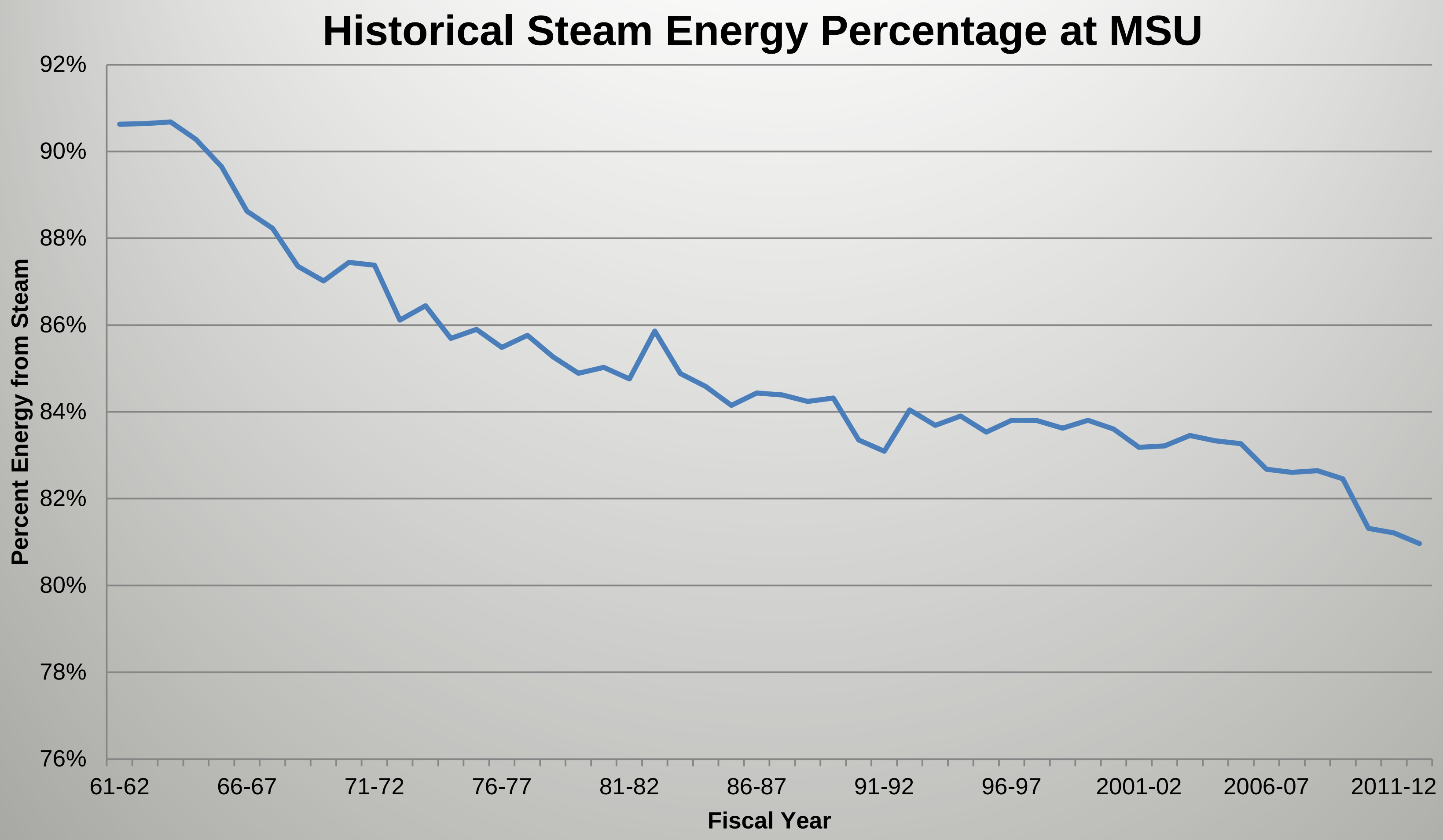
Electrical Only, BTU/KWH (%)

	Coal	Natural Gas	Petroleum
Steam Generator	10,107 33.8%	10,385 32.9%	10,359 32.9%
Gas Turbine	--	11,499 29.7%	13,622 25.0%
Internal Combustion	--	9,991 34.2%	10,416 32.8%
Combined Cycle	--	7,615 44.8%	10,195 33.5%

$$HR_{thermal} = \frac{3{,}412\ BTU/KWH}{\eta_{\ th}} = \frac{3{,}412}{0.653} = 5{,}225 \text{ BTU/KWH}$$

But there is a problem with this reasoning, you must know your process very well before declaring success and reductions.

T.B. Simon CHP plant



We are out of balance and it’s getting worse

Time to rethink and get efficiency up and emissions down

Simon Plant CHP Balance

Improving Heat Rate

A plant in perfect steam / electric balance would produce only as much electricity to satisfy campus steam demand

The remainder would have to come from grid purchase or more efficient electrical production

CHP Balance

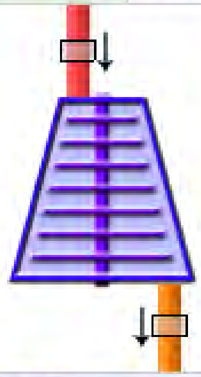
- Backpressure steam turbine generators do not have condensing. They must be run in CHP balance.
- A glimpse at a plant in balance is to expand this idea over the entire steam demand.
- This case shows generation of 1MW of electricity for each 19,450 lbs of steam sent to campus. It can be done at a heat rate of 4,550 BTU / KWH (75%)

Steam Turbine Calculator

Calculates the energy generated or steam outlet conditions for a steam turbine.

Solve for:		
Isentropic Efficiency		
Inlet Steam		
Pressure*	900	psig
Temperature *	835	°F
Turbine Properties		
Selected Turbine Property	Mass Flow	
Mass Flow *	19.45	klb/hr
Generator Efficiency *	90	%
Outlet Steam		
Pressure*	90	psig
Temperature *	385	°F
* Required	Enter	[reset]

Inlet Steam		Mass Flow	19.5 klb/hr
Pressure	900.0 psig	Sp. Enthalpy	1,413.9 btu/lbm
Temperature	835.0 °F	Sp. Entropy	1.596 btu/lbm/R
Phase	Gas	Energy Flow	27.5 MMBtu/hr

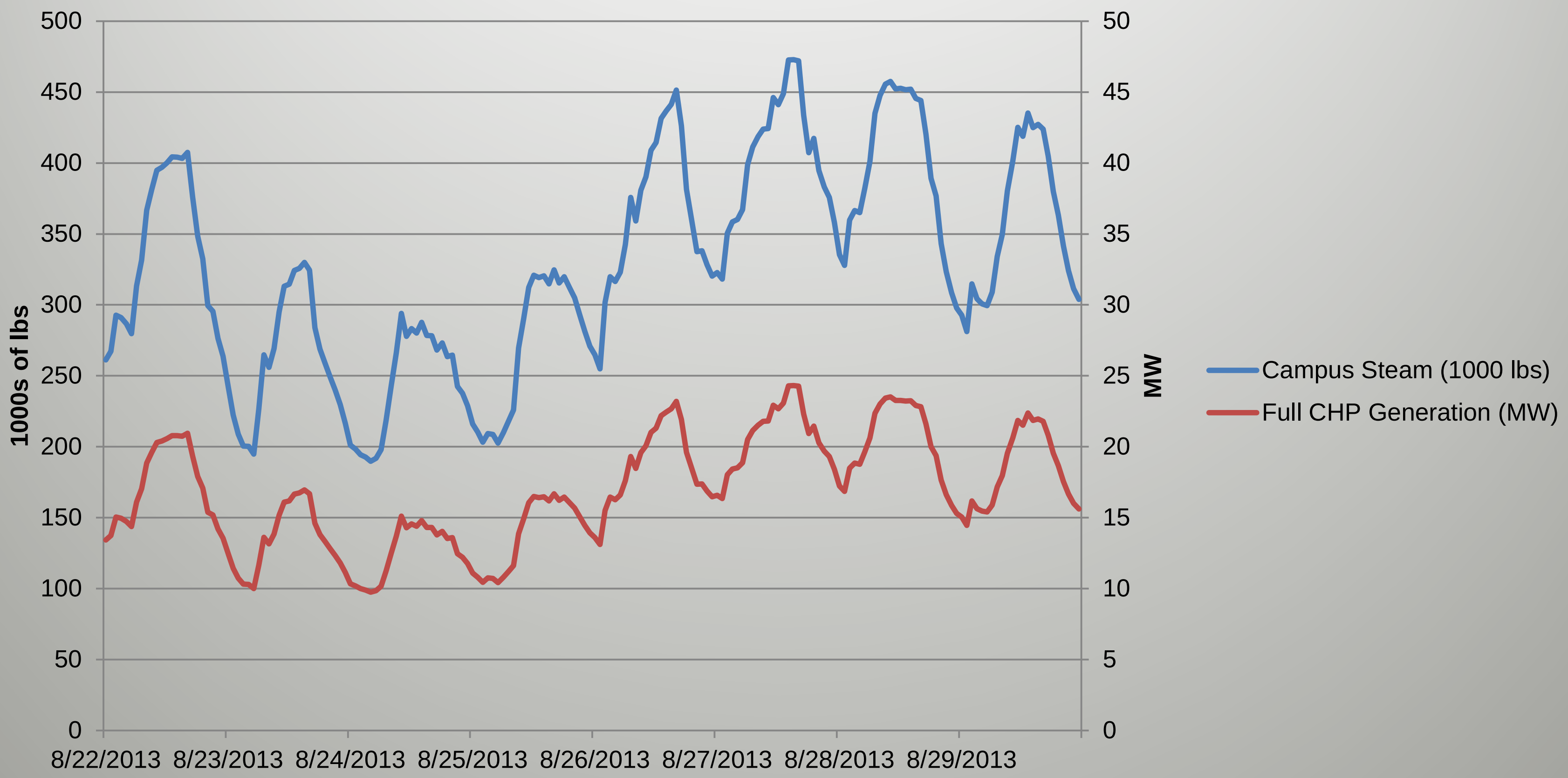


Isentropic Efficiency	85.3 %
Energy Out	3.8 MMBtu/hr
Generator Efficiency	90.0 %
Power Out	1,000.2 kW

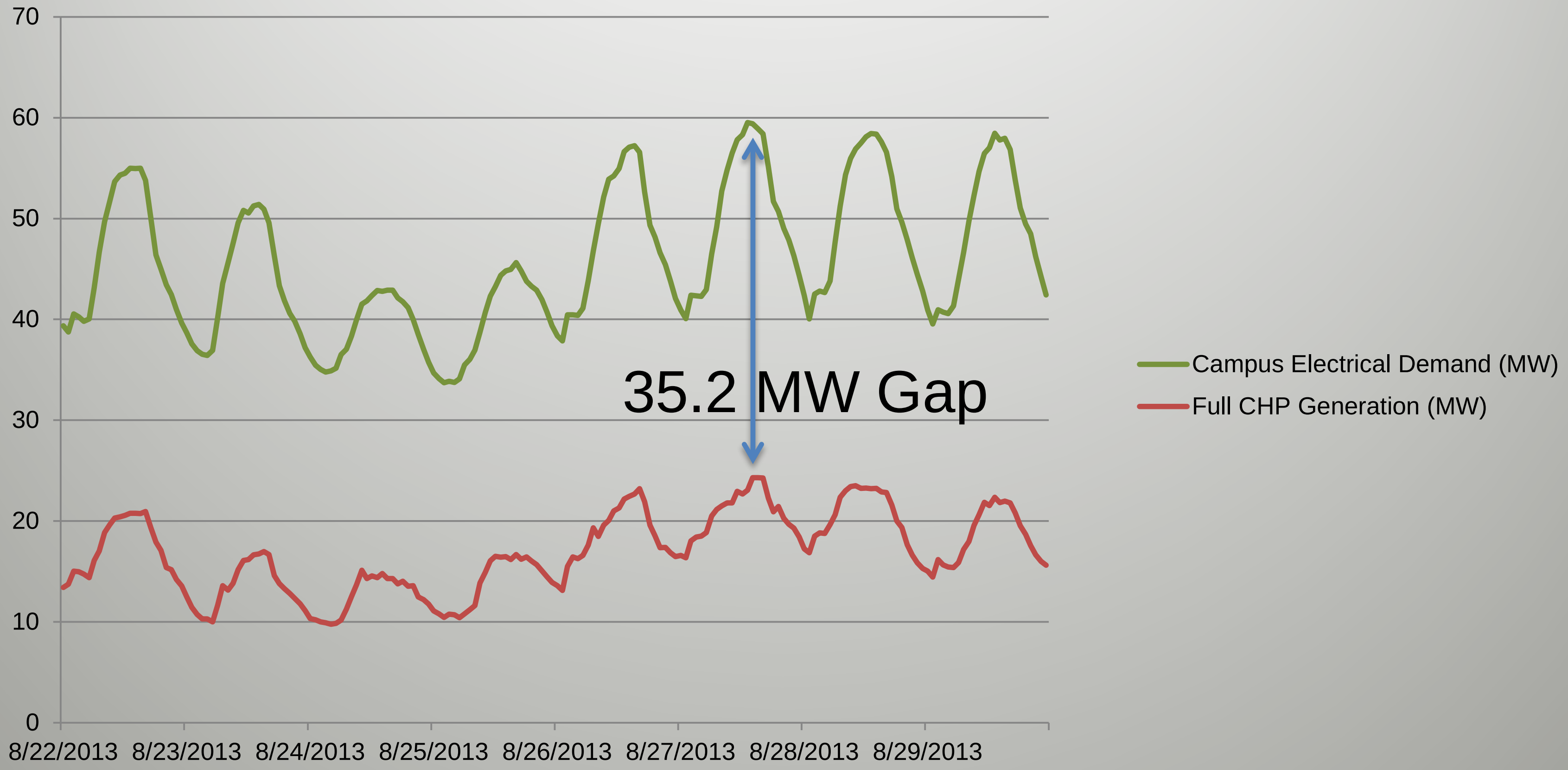
Outlet Steam		Mass Flow	19.5 klb/hr
Pressure	90.0 psig	Sp. Enthalpy	1,219.0 btu/lbm
Temperature	385.0 °F	Sp. Entropy	1.637 btu/lbm/R
Phase	Gas	Energy Flow	23.7 MMBtu/hr

http://www4.eere.energy.gov/manufacturing/tech_deployment/amo_steam_tool/equipTurbine

CHP generation at peak annual campus electrical demand



CHP generation and electrical demand



The gap?

- The gap is caused by a demand for more electrical power than the existing CHP process can most efficiently support.
- The gap is filled presently with conventional power generation by Rankine cycle with condensing which has a heat rate of 10,385 BTU/KWH

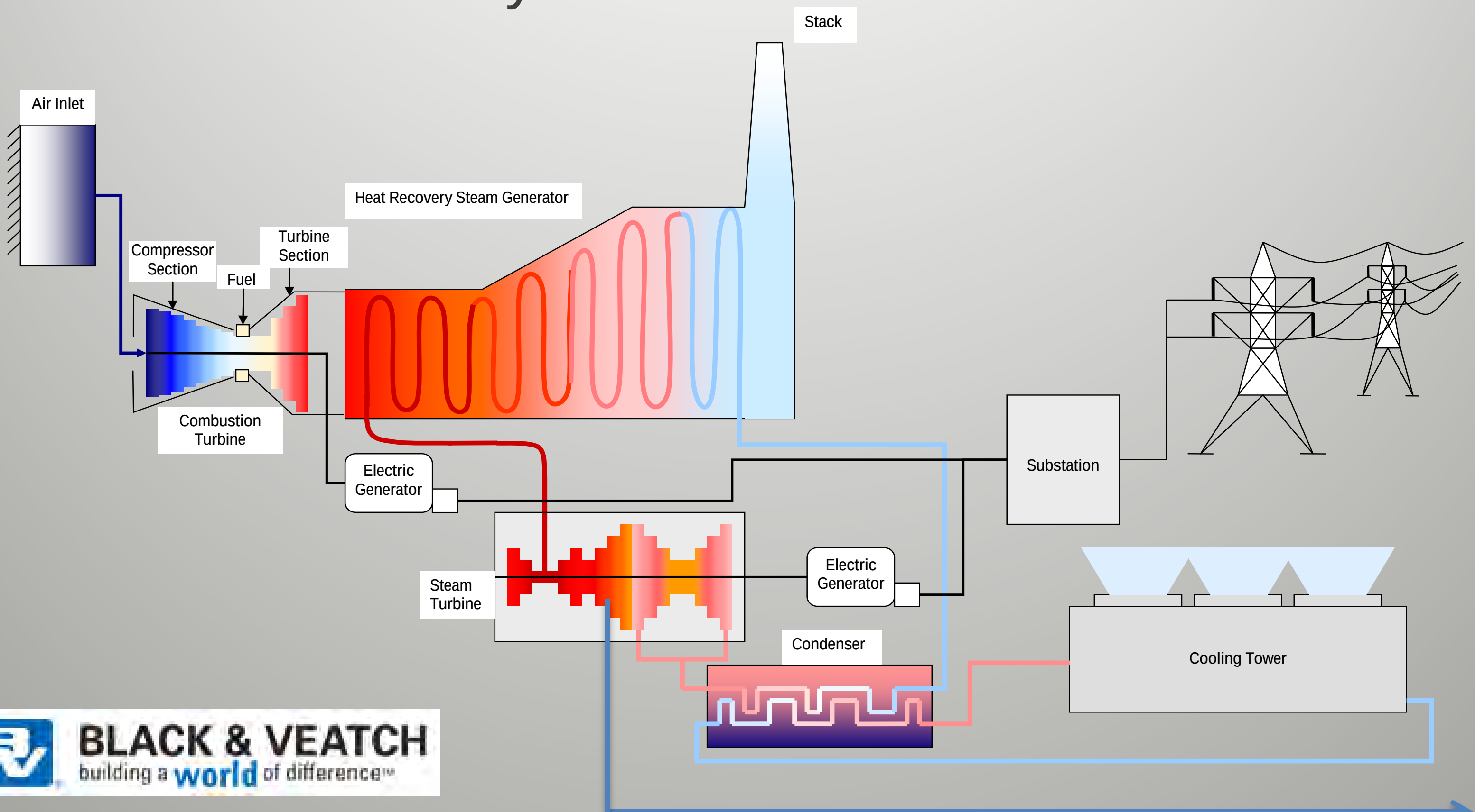
Closing the gap

- It could be filled with more efficient combined cycle operation at 7,165 BTU/KWH

	Coal	Natural Gas	Petroleum	Nuclear
Steam Generator	10,107	10,385	10,359	10,479
Gas Turbine	--	11,499	13,622	--
Internal Combustion	--	9,991	10,416	--
Combined Cycle	--	7,615	10,195	--

What is combined cycle CHP?

Combined cycle is the coupling of the Brayton cycle with the Rankine Cycle.



Extracted steam to campus

Future

Using heat rate

- If we were to offload the electrical demand beyond the need for steam to Combined cycle generation, we predict:

- Pure CHP = 24,300 KW x 4550 BTU/ KWH = 110 million BTU / Hour
- Combined Cycle = 35,200 KW x 7,615 BTU/KWH = 268 million BTU / Hour
- Total is 378 million BTU / Hour

It would have been

- Pure CHP = 24,300 KW x 4550 BTU/ KWH = 110 million BTU / Hour
- Conventional Condensing = 35,200 KW x 10,385 BTU/KWH = 366 million BTU / Hour

- Total is 476 million BTU / Hour

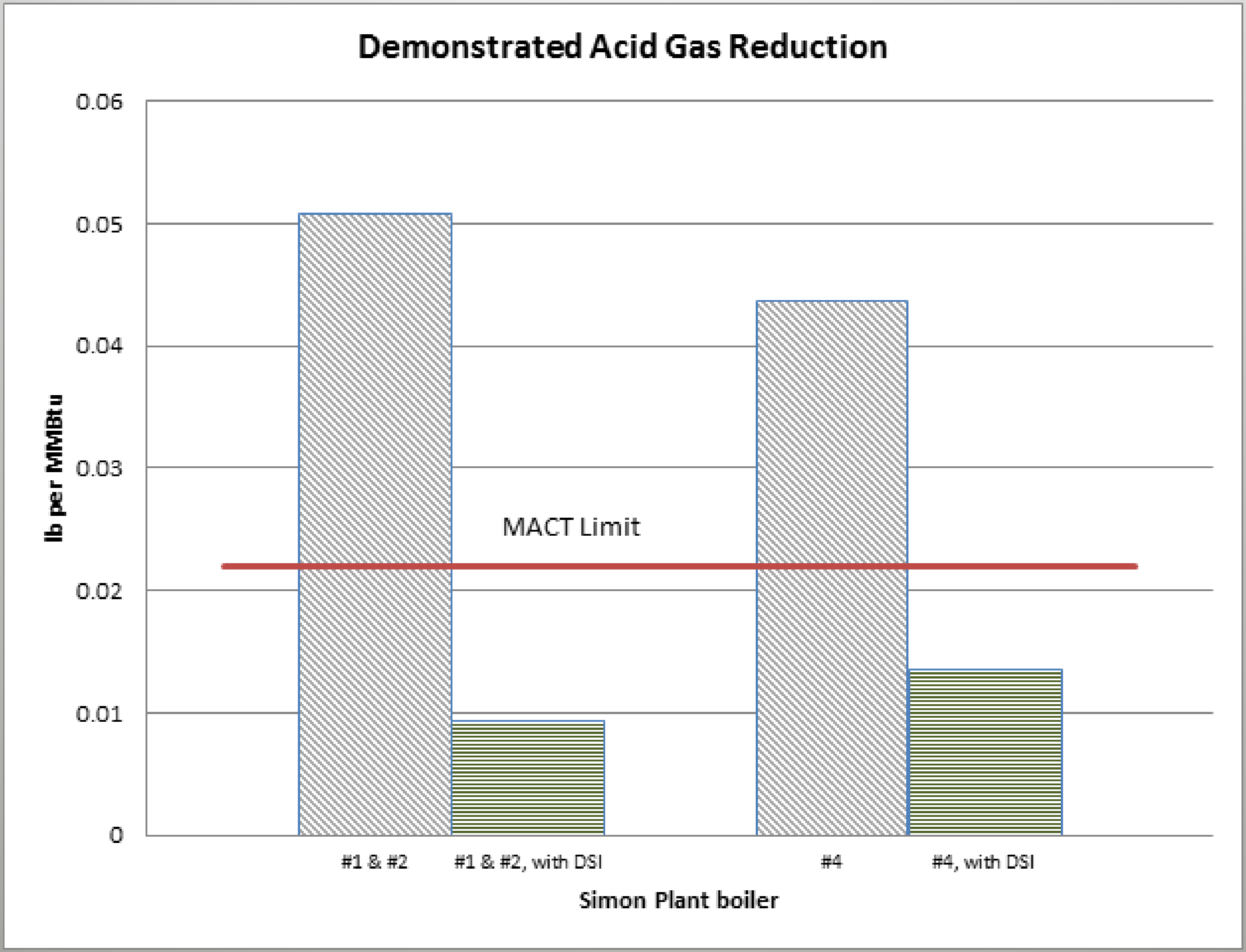
Reduction

- 476 – 378 = 98 million BTU / Hour or a 20.6% drop in fuel input and emissions.

Further improvement might come from full replacement to combined cycle CHP.


MSU
DSI
MACT

DSI Results

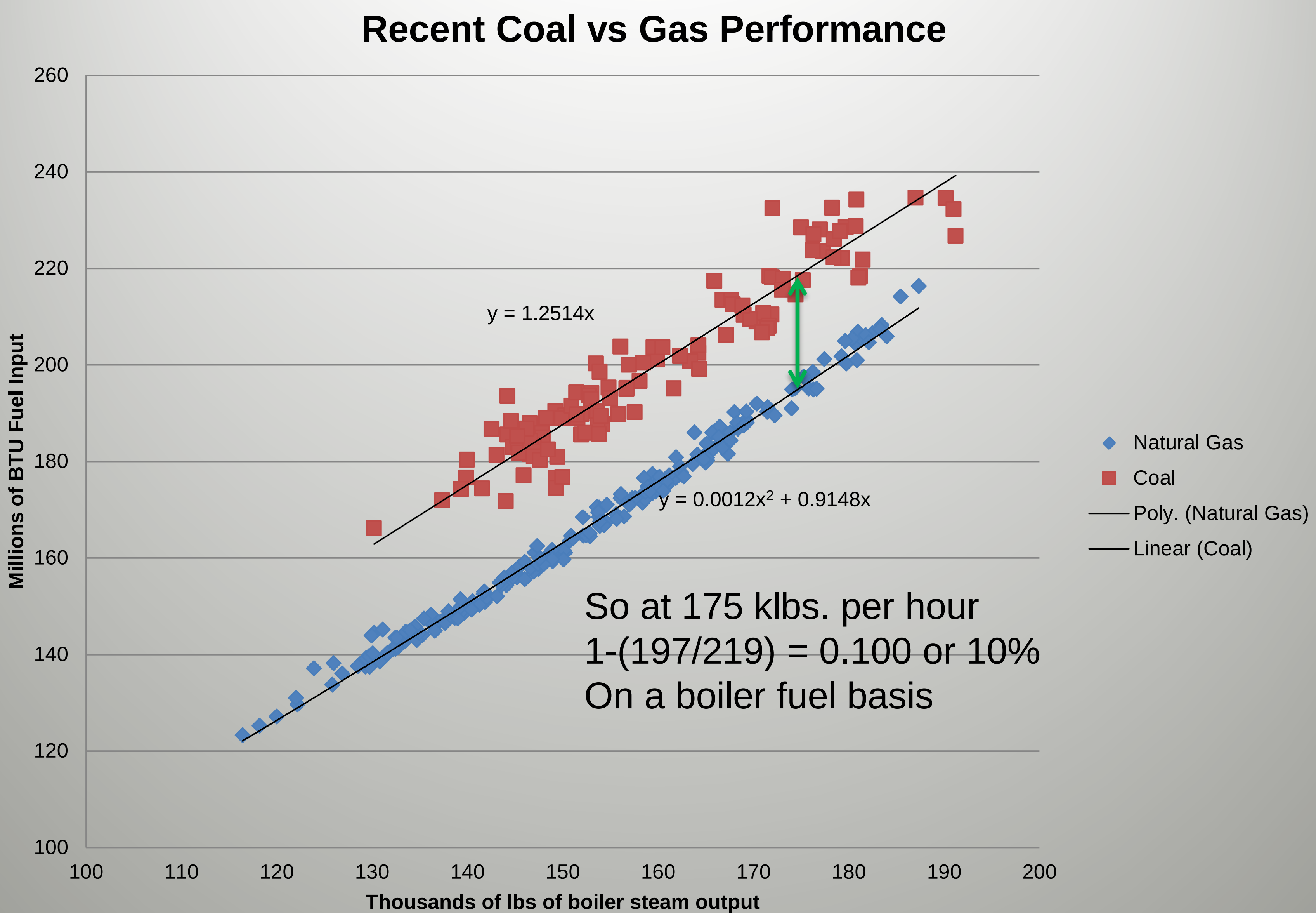

Demonstrated Acid Gas Reduction
lb per MMBtu
0.06
0.05
0.04
0.03
0.02
0.01
0
MACT Limit
#1 & #2
#1 & #2, with DSI
#4
#4, with DSI
Simon Plant boiler

Circulating Fluidized Bed Boiler DSI

TRC
Results you can rely on

Test Conditon M320	HCl Emission Rate lb/MMBtu	Average DSI Flow Rate lbs/hr
Baseline 8/17/13		
Run 1	0.0389	0
Run 2	0.0437	0
Run 3	0.0453	0
Run 4	0.0473	0
Average	0.0438	0
Injection day 1 on Lime 8/18/13		
Run 1	0.0180	217
Run 2	0.0154	229
Run 3	0.0136	218
Average	0.0157	221
Injection day 2 on SBC 8/19/13		
Run 1	0.0091	279
Run 2	0.0081	223
Run 3	0.0077	255
Average	0.0083	252

1 lb/MMBtu emission rate using CO_2 based F-factor

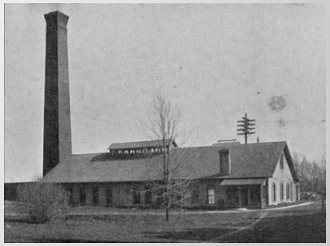

Recent Coal vs Gas Performance
Millions of BTU Fuel Input
260
240
220
200
180
160
140
120
100
100
110
120
130
140
150
160
170
180
190
200
Thousands of lbs of boiler steam output
y = 1.2514x
y = 0.0012x2 + 0.9148x
So at 175 klbs. per hour
1-(197/219) = 0.100 or 10%
On a boiler fuel basis
Natural Gas
Coal
Poly. (Natural Gas)
Linear (Coal)

Thank you for your kind attention

This presentation is dedicated to the men and women of the T.B. Simon Heat and Power Plant who kept MSU powered through the toughest Michigan winter in several decades.

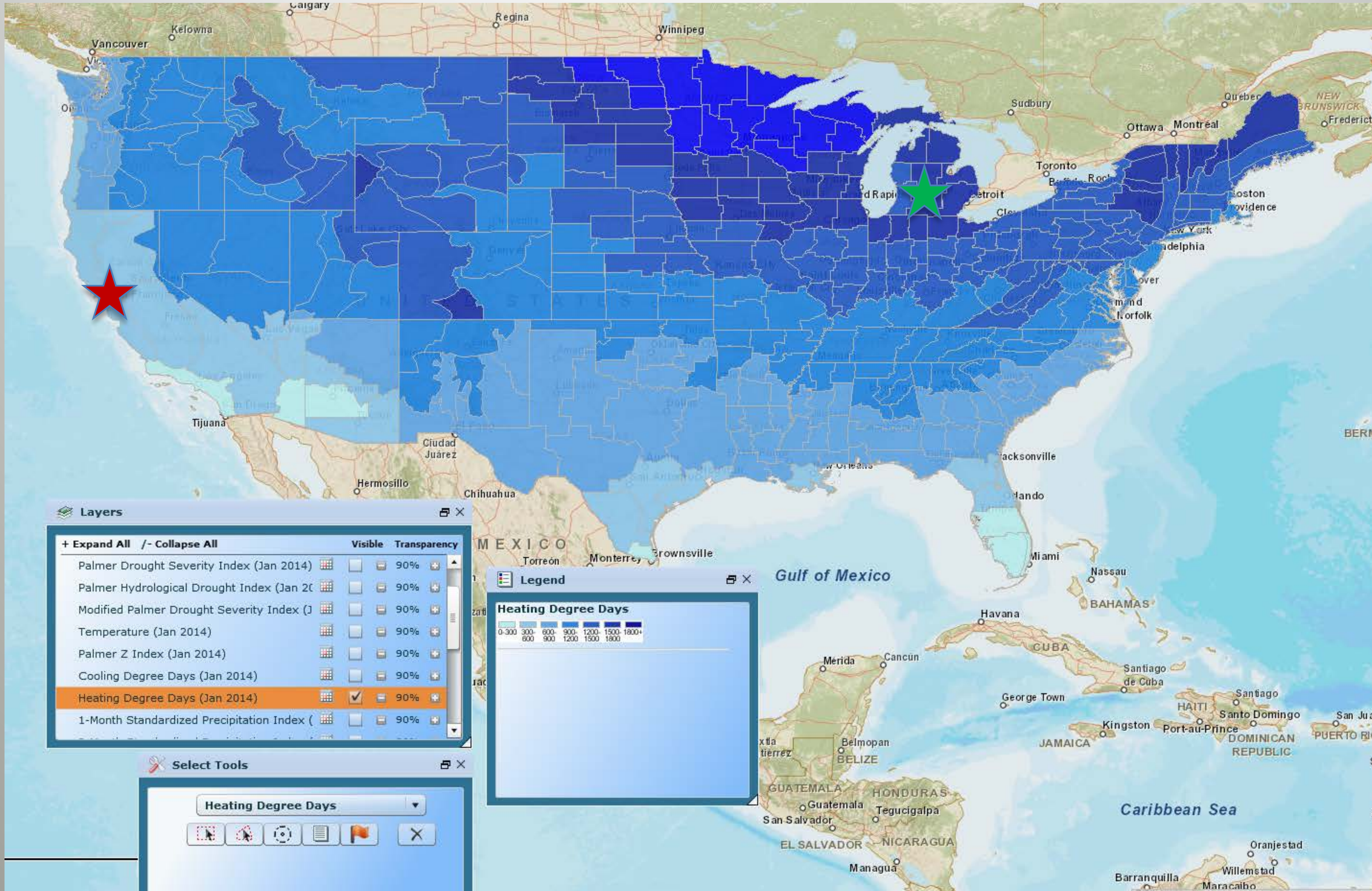
Backup Slides

Simon plant detail



- Built in 1965, 5th in the series of MSU plants.
- 4 boilers (1,200 kpph max) of steam 900 psig, 835F
- 1 HRSG (115 kpph max) with duct firing.
- All boilers on a common header
- 85 MW across 5 steam turbine generators
- 13.5 MW on 1 NG CT turbine (black start)
- 21 MW grid tie-line with local utility
- 318,028 MWH of electrical production in 2012

Know your zone for heating



A zone comparison

Institution	Stanford University	Michigan State University
Location	Palo Alto, CA	East Lansing, MI
Coordinates	37.4292° N, 122.1381° W	42.7336° N, 84.5467° W
Annual Heating Degree Days, 65°F base	2832	7041
Annual Cooling Degree Days, 65°F base	303	556
Climate zone	Mediterranean	Humid continental
Number of campus buildings	690	532
Space, square feet	14.8	21.7 million
Plant electric capacity, megawatt	49.0	98.5

Factor of 2.5 in heating degree days

In zones with lower heating degree days, you want to consider the total thermal process efficiency carefully

Power and Water T. B. Simon Power Plant
Facts and Figures

STEAM GENERATORS

UNITS 1 & 2	
Manufacturer	Wickes Boiler Company
Design	Pulverized Coal
Start-Up	1965 -1966
Capacity	250,000 lb. per hour
Operating Temperature	835° F @ Superheater Outlet
Operating Pressure	900 P.S.I.G.
Primary Fuels	Pulverized Coal - Natural Gas
Coal Consumption at Full Load	12 tons per hour

UNIT 3	
Manufacturer	Erie City Energy Division of Zurn Industries
Design	Pulverized Coal
Start-Up	1975
Capacity	350,000 lb. per hour
Operating Temperature	835° F @ Superheater Outlet
Operating Pressure	900 P.S.I.G.
Primary Fuels	Pulverized Coal - Natural Gas
Coal Consumption at Full Load	20 tons per hour

UNIT 4	
Manufacturer	Tampella Power Corporation
Design	Circulating Fluidized Bed
Start-Up	1993
Capacity	350,000 lb. per hour
Operating Temperature	835° F @ Superheater Outlet
Operating Pressure	900 P.S.I.G.
Primary Fuels	Coal - Natural Gas
Coal Consumption at Full Load	20 tons per hour
Limestone Consumption at Full Load	4 tons per hour

UNIT 6	
Manufacturer	Nebraska Boiler
Design	Heat Recovery Steam Generator
Start-Up	2006
Capacity	115,000 lb. per hour
Operating Temperature	835° F @ Superheater Outlet
Operating Pressure	900 P.S.I.G.
Primary Fuels	Natural Gas
Gas Consumption at Full Load	4200 lb. per hour

Power and Water T. B. Simon Power Plant
Facts and Figures

TURBINE GENERATORS

UNITS 1 & 2	
Manufacturer	Turbine – DeLaval Generator - Electric Machinery Inc
Description	3600 RPM, fully condensing, single automatic extraction. Steam turbine with direct connected electric generator and D.C. exciter.
Throttle Steam Conditions	825° F, 850 P.S.I.G.
Turbine Controlled Extraction Pressure	90 P.S.I.G.
Generator Electrical Characteristics	12.5 MW, .80 power factor, 13,800 volts, 3 phase, 60 Hertz, 3600 RPM, air cooled.

UNIT 3	
Manufacturer	General Electric Co.
Description	3600 RPM, Straight, non-condensing steam turbine with direct connected electric generator, static exciter
Throttle Steam Conditions	825° F, 850 P.S.I.G.
Turbine Controlled Extraction Pressure	90 P.S.I.G.
Generator Electrical Characteristics	3600 RPM, 15 MW, .85 power factor, 13,800 volts, 3 phase, 60 Hertz, 3600 RPM, 250 volts

UNIT 4	
Manufacturer	General Electric Co.
Description	Generator controlled General Electric extracting condensing steam turbine with direct coupled electric generator and brushless static exciter.
Throttle Steam Conditions	825° F, 850 P.S.I.G.
Turbine Controlled Extraction Pressure	90 P.S.I.G.
Generator Electrical Characteristics	3600 RPM, 21 MW, .85 power factor, 13,800 volts, 3 phase, 60 Hertz

Power and Water T. B. Simon Power Plant
Facts and Figures

TURBINE GENERATORS

UNIT 5	
Manufacturer	Dresser-Rand
Description	Condensing, single controlled extraction steam turbine with direct coupled electric generator with a brushless static exciter.
Throttle Steam Conditions	825° F, 865 P.S.I.G.
Turbine Controlled Extraction Pressure	90 P.S.I.G.
Generator Electrical Characteristics	3600 RPM, 24 MW, .85 power factor, 13,800 volts, 3 phase, 60 Hertz

Manufacturer	Solar Turbines Inc.
Description	Single shaft axial flow gas turbine with reduction gear and completely integrated ABB electric generator with a brushless rotating exciter
Primary Fuel	Natural Gas
Fuel Consumption at Full Load	6,500 lb. per hour
Emissions Control	Dry Low NOx Burners
Pressure Ratio	16:1
Generator Electrical Characteristics	3600 RPM, 13.5 MW, .85 power factor, 13,800 volts, 3 phase, 60 Hertz

Power and Water T. B. Simon Power Plant Facts and Figures

GENERAL INFORMATION

Cubic Content of Main Building	6,102,000 cubic feet (Units 1-4)
Ground Area of Main Building	40,000 square feet (?)
Height of Main Building	109 feet
Height of Boilers	Units 1 & 2 - 80 feet Unit 3 - 97 feet Unit 4 - 125 feet
Bunker Coal Storage Capacity	2,000 tons
Maximum Coal Storage at Site	100,000 tons
Coal System Capacity	200 tons per hour
Cooling Towers	East - 6 cells capable of cooling 25,000 GPM of water with 2,140,000 cubic feet per minute of air Center - 4 cells cooling 20,000 gpm of water with 1,560,000 cubic feet per minute of air West - 3 cells cooling 19,500 gpm of water with 1,633,000 cubic feet per minute of air
Pollution Equipment	Units 1 & 2 - 8 Module, 2400 bag fabric filter Unit 3 - 4 Field Hot Side, Electrostatic precipitator Unit 6 - Dry Low NOx Burners

WATER CAPACITIES

	Normal Water Level	Hydrostatic Test Water Level
Units 1 & 2	15,500 gal	19,233 gal
	129,115 lbs	160,215 lbs
Unit 3	21,608 gal	26,890 gal
	180,211 lbs	224,263 lbs
Unit 4	16,500 gal	23,023 gal
	136,941 lbs	191,782 lbs
Unit 6	3,975 gal	6,867 gal
	33,000 lbs	57,000 lbs

PLANT CAPACITIES

Steam (5 boilers)	1,315,000 lbs/hr
Electricity (6 turbine generators)	98.5 MW
CPCO Tie Line	25 MW

Power and Water T. B. Simon Power Plant Facts and Figures

FISCAL YEAR 2011-2012 PLANT DATA

PEAK DEMANDS	
Boiler Steam	825,500 lbs/hr
Sendout Steam	541,360 lbs/hr
Electricity	60,880 KW

TOTAL PRODUCTION	
Boiler Steam	4,568,883,000 lbs
Sendout Steam	2,496,724,000 lbs
Electricity	318,028,000 KWH

FUEL CONSUMPTION	
Coal	113,547 tons
Natural Gas	345,153 KCFT
Biofuels	5,510 tons

ELECTRICAL SYSTEM	
Number of Circuits	18 - 13.8 KV to campus from plant 5 - 4160V circuits form 1 substation
Length of Cable	71.47 miles

WATER SYSTEM PRODUCTION	
Well Production	1,325,000,000 Gallons
Peak System Demand	5,600 GPM

WATER SYSTEM GENERAL INFORMATION	
Number of Wells	Eighteen
Bore Depth	Nominally 400’
Bore Diameter	9”, 12”, 14” and 16”
Average :Pump Settings	250’
Pumps	8” Dia. 8-Stage, 9-Stage Vert. Turbine
Motors	50 Hp, 60 Hp, 75 Hp, 100 Hp 480 V, 3-Phase
Average Pump Capacity	450 GPM
Well Transmission Main	8 miles, 10”, 12”, 14”, 16”
Water Storage	1,000,000 Gal. Underground
Distribution Pumps	Four
Capacity	3400 GPM each
Motors	200 Hp, 480V, 3-Phase
Distribution System	Approximately 65 miles
Steam Lines	20 miles

Simon plant P&ID