City Hospital – Campus Development

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The Pennsylvania State University

Architectural Engineering
Mechanical Option

Senior Thesis Presentation 2008

Thesis Advisor: James D. Freihaut, Ph.D.

Presentation Outline

- Project Background
- Existing Mechanical System
- Alternate Mechanical System
- Acoustic Breadth
- Future Considerations
- Life Cycle Cost
- Conclusion

- Southeast Pennsylvania
- 30-year 3 million SF
  - Campus Development Plan
    - 1 million SF of research space
    - 1 million SF of office space
    - 1 million SF of support service & parking space

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Phase 1

Completed in March 2008

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Phase 1 - Vivarium

- 176,000 SF on 3 levels below grade

- contains research space & animal suite

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Phase 1 – Central Utility Plant

- 59,500 SF on 3 levels below grade

- contains MEP infrastructures to support City Hospital campus

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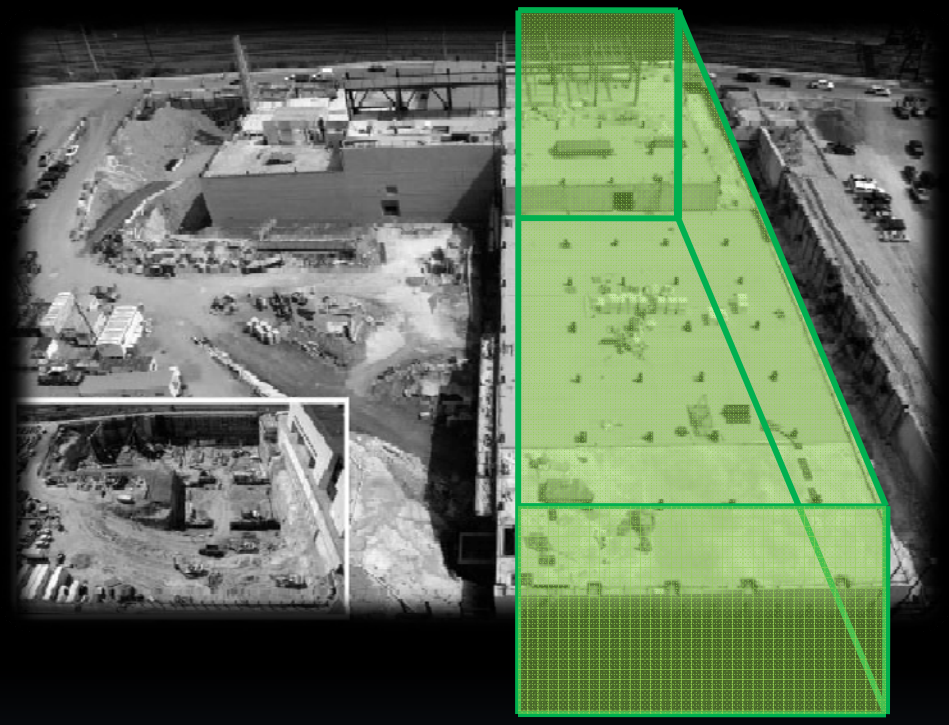
Phase 2 – Research Lab



- construction began July 2008, above P1 - Vivarium

- 250,000 SF on 7 floors above ground

- contains laboratory & office spaces

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Air System

Phase 1 - vivarium
(6) 100,000 cfm 100% OA AHU
(3) 120,000 cfm EAHU w/ heat recovery

Phase 2 - laboratory
(1) 100,000 cfm 100% OA AHU
(4) 50,000 cfm 100% OA AHU
(3) 100,000 cfm EAHU w/ heat recovery

Phase 2 - office
(4) 50,000 cfm AHU w/ recirculation

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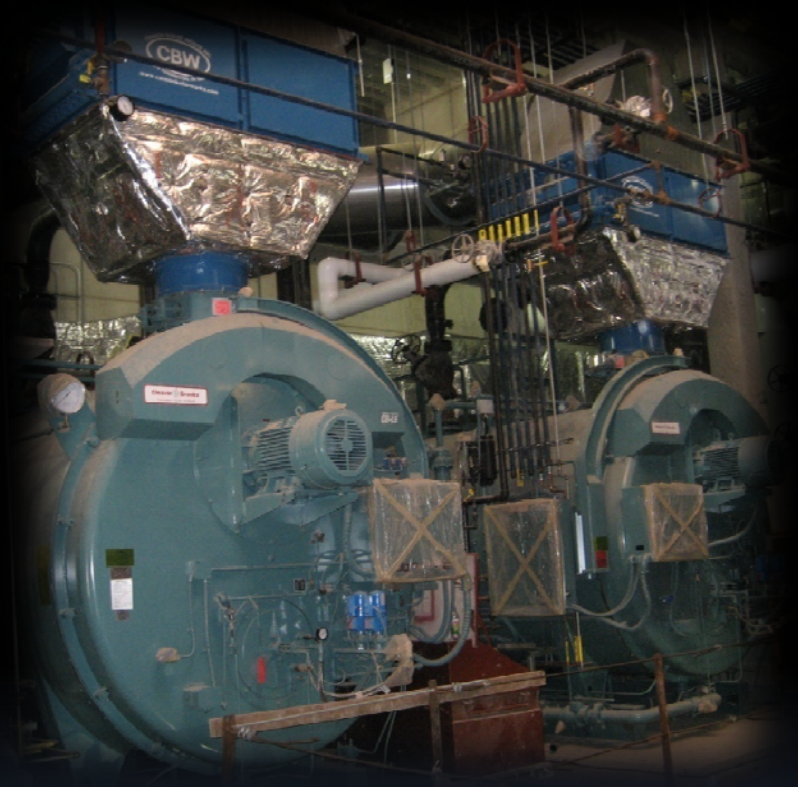
Boiler Plant

(4) 32 MMBtuh dual fuel steam boilers



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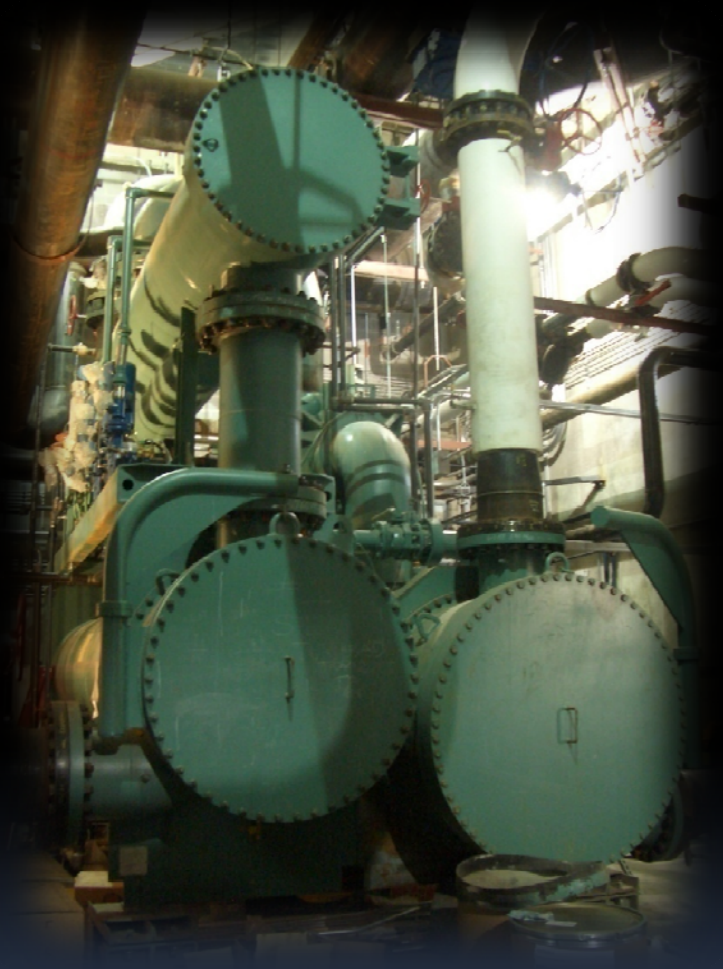
Boiler Plant

(4) 32 MMBtuh dual fuel steam boilers

Chiller Plant

(1) 2,000 ton electric centrifugal
(1) 2,000 ton steam turbine



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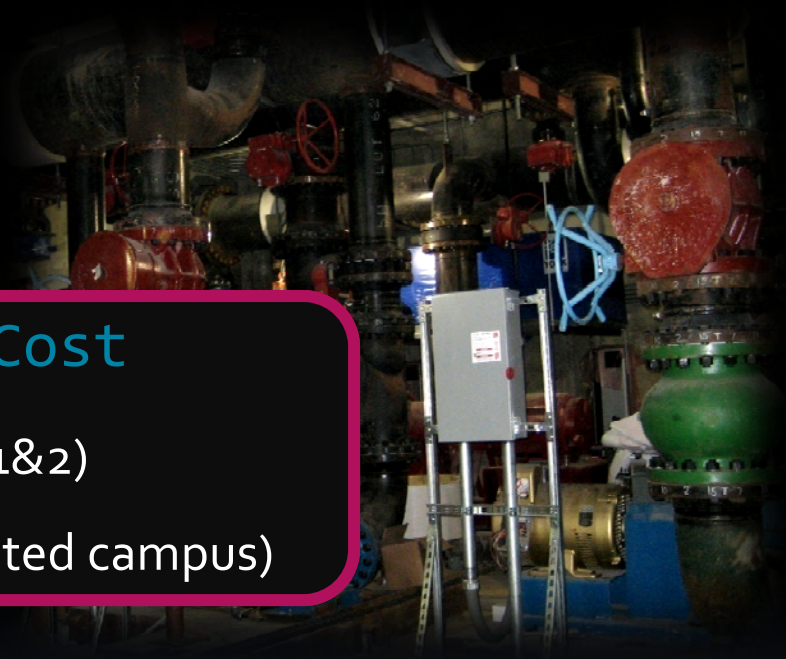
Energy Saving Designs

- VAV fume hoods
- VSD fans & pumps
- Boiler stack economizer
- Glycol loop sensible heat recovery



Annual Energy Cost

~ **$4.35** million (Phase 1&2)

~ **$20.5** million (completed campus)

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Design Objectives

- Reduce energy usage & cost
- Optimize economic viability
- Maintain occupants' health & thermal comfort
- Maintain system's flexibility & ability to expand
- Lessen environmental impacts

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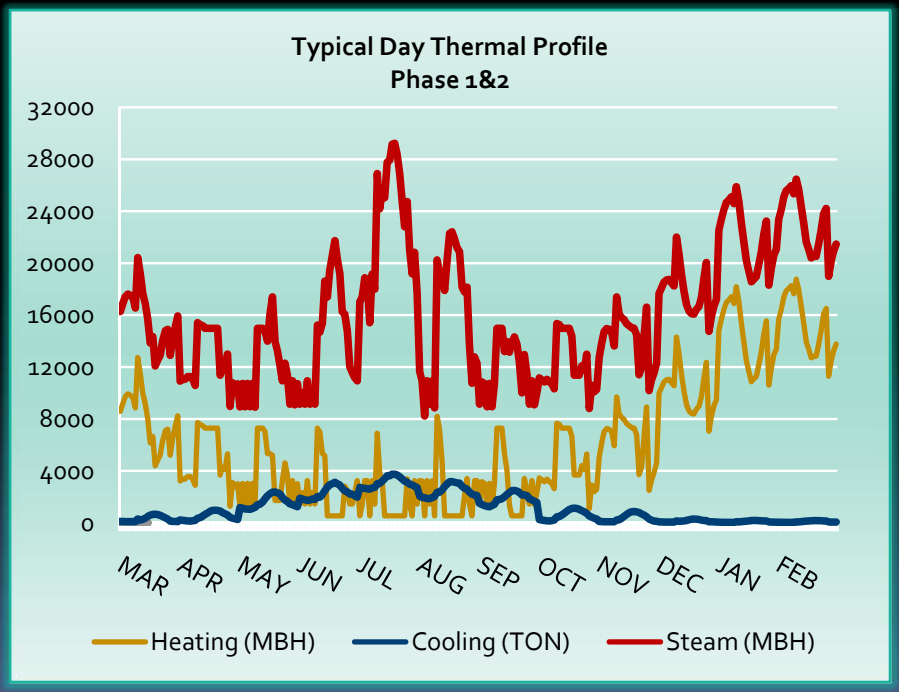
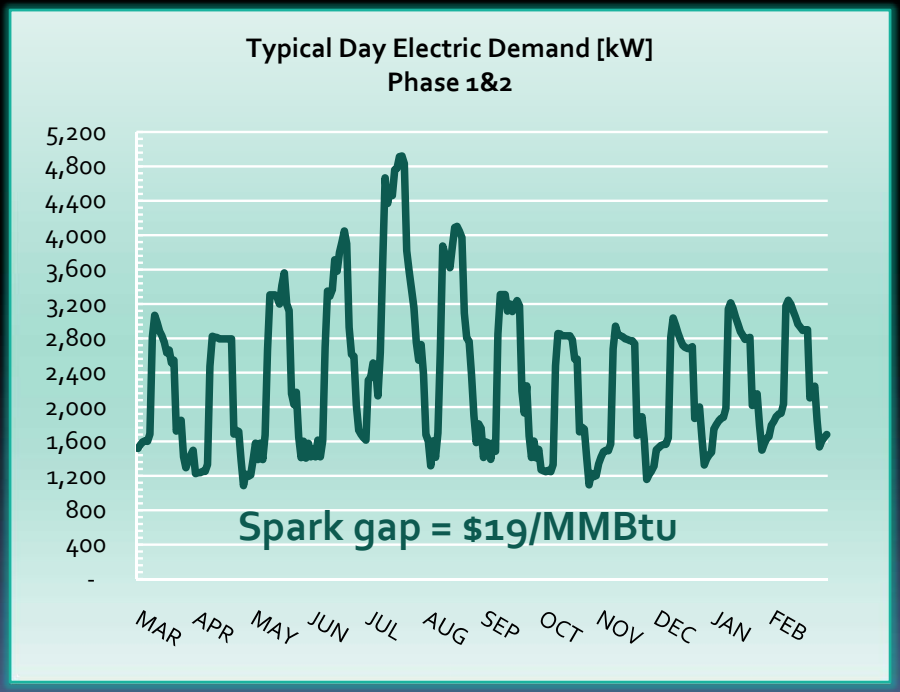
Alt. 2: Cogeneration (CHP)

Most practical when

- A central plant already in place
- A need for process heat
- Spark-Gap > $12/MMBtuh





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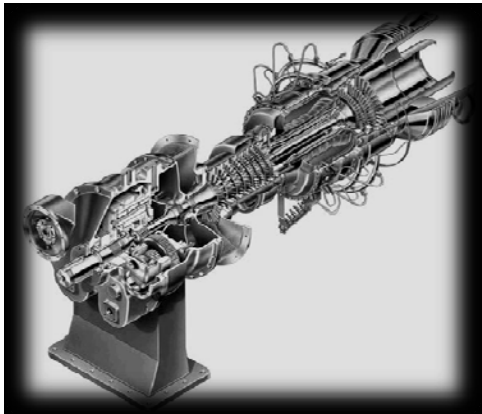

CHP Components

3 Main Parts

- Prime mover
- Electric generator
- Heat recovery steam generator (HRSG)

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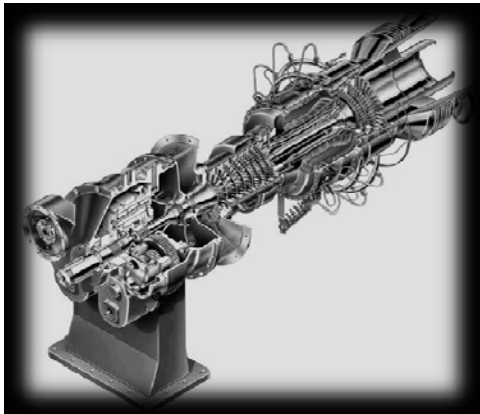

Prime Mover Selection

Prime Mover Summary		
Technology	**Gas Turbine**	**Fuel Cell**
Power Efficiency	22 – 36%	30 – 63%
Overall Efficiency	70 – 75%	65 – 80%
Typical Capacity (MW)	1 – 500	0.01 – 2
Typical Power to Heat Ratio	0.5 – 2	1 – 2
Part Load	Poor	Good
CHP Installed Cost ($/kW)	800 – 1,800	2,700 – 5,300
O&M Cost ($/kWh)	0.003 – 0.0096	0.005 – 0.04
Hours to Overhauls	30,000 – 50,000	10,000 – 40,000
Start-up Time	10 min – 1 hr	3 hr – 2 days
Fuels	Natural gas	Hydrogen
	Bio gas	Bio gas
	Propane	Propane
	Fuel oil	Methanol
Noise	Moderate	Low

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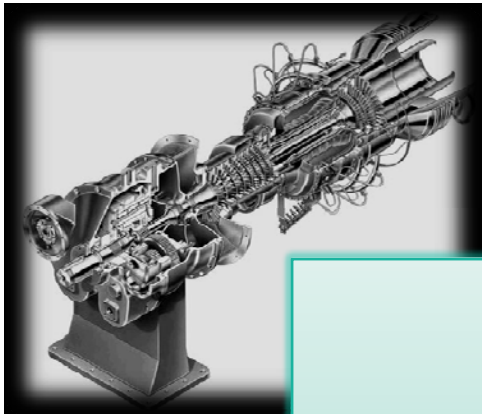
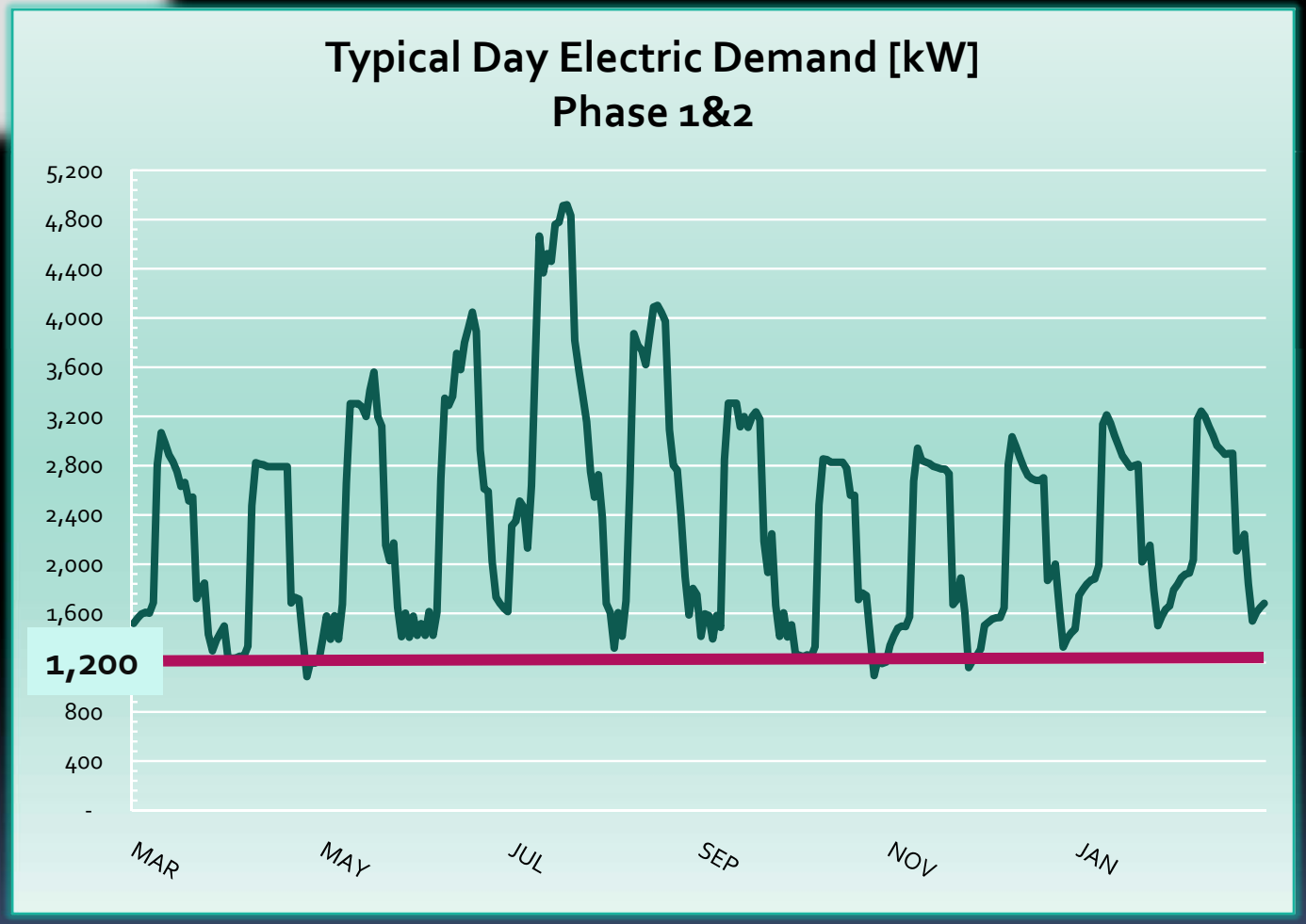


Generator Selection



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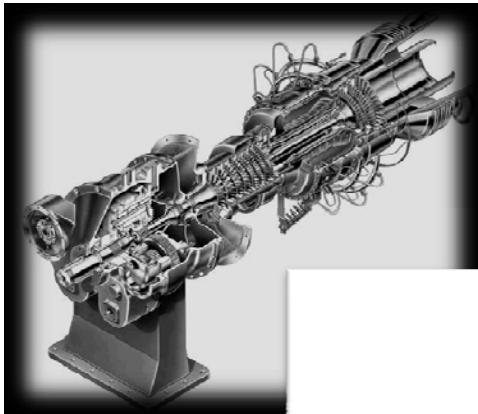
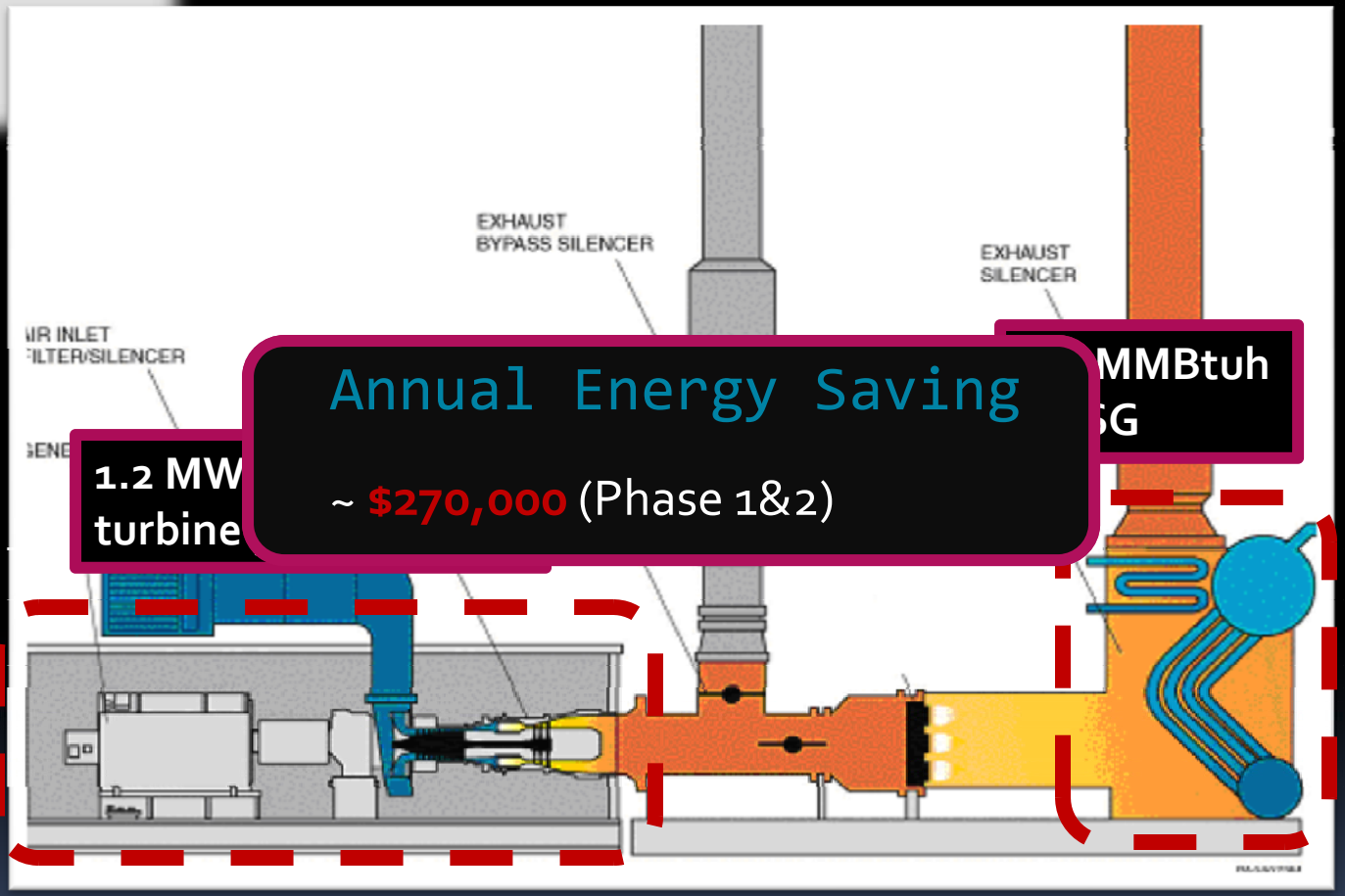


CHP Equipment Set



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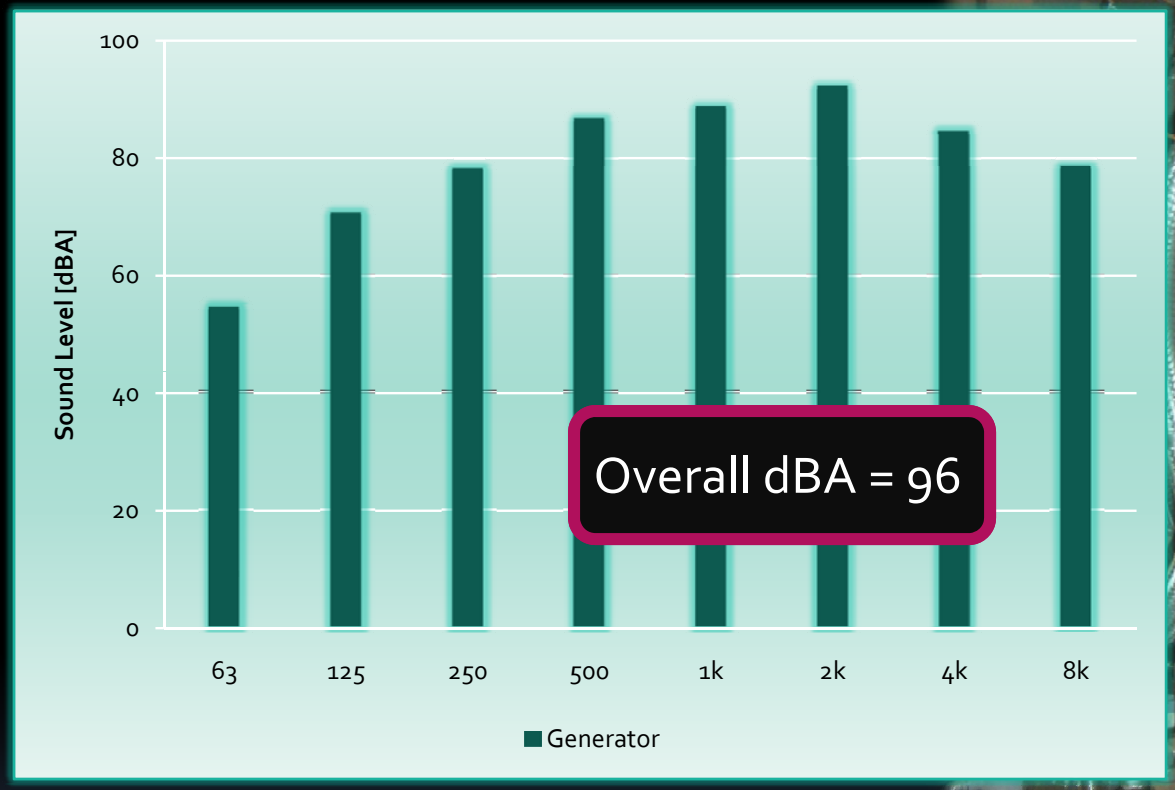
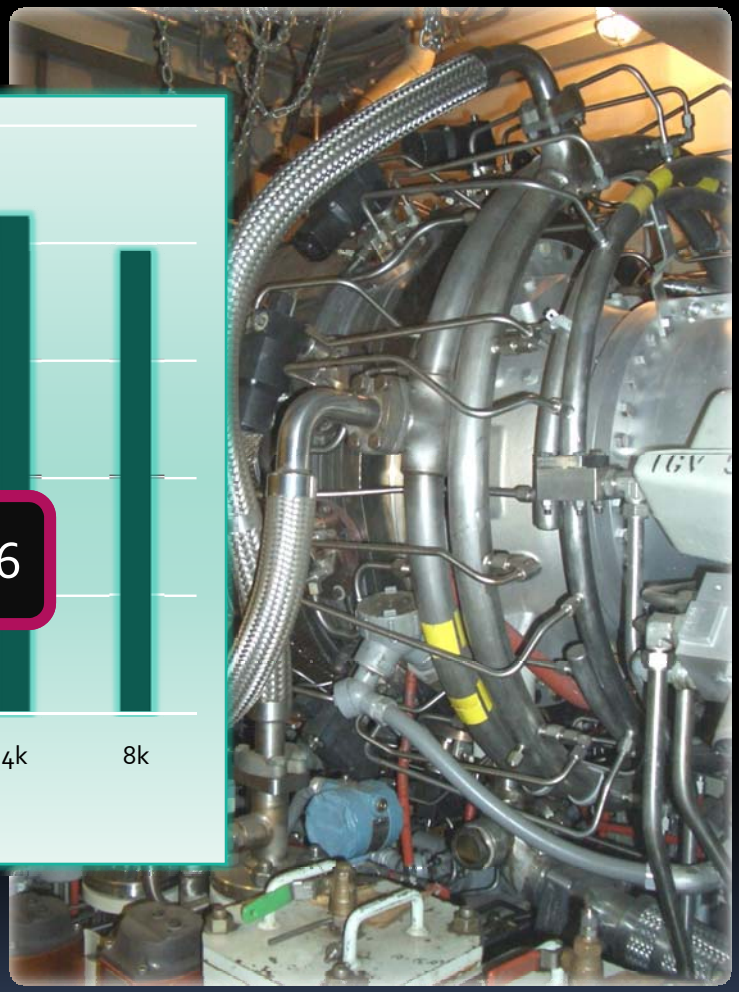
Sound Level





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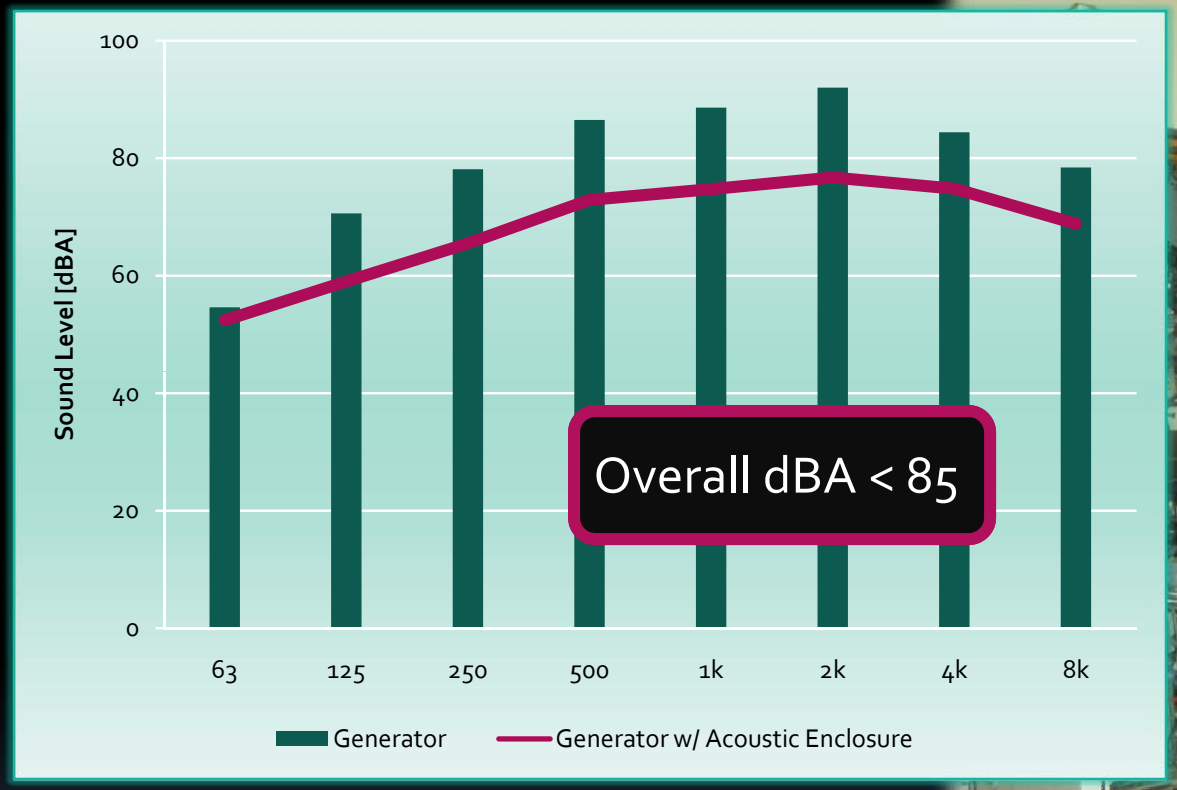
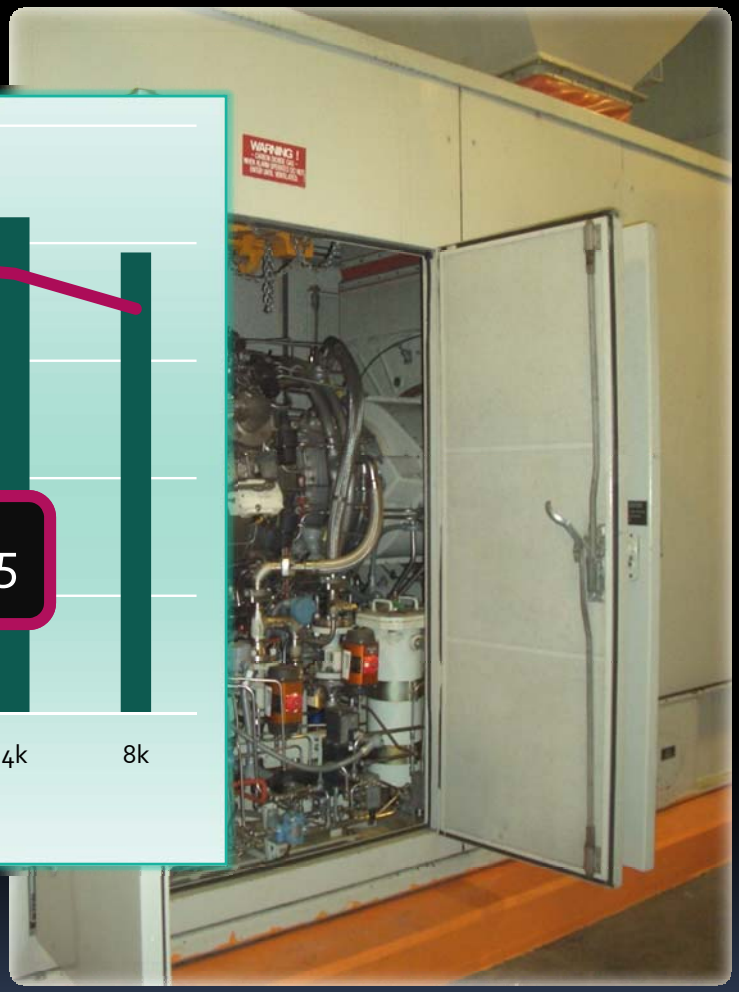
Sound Level





- optional inlet & exhaust silencers reduce noise level below ambient outdoor noise level

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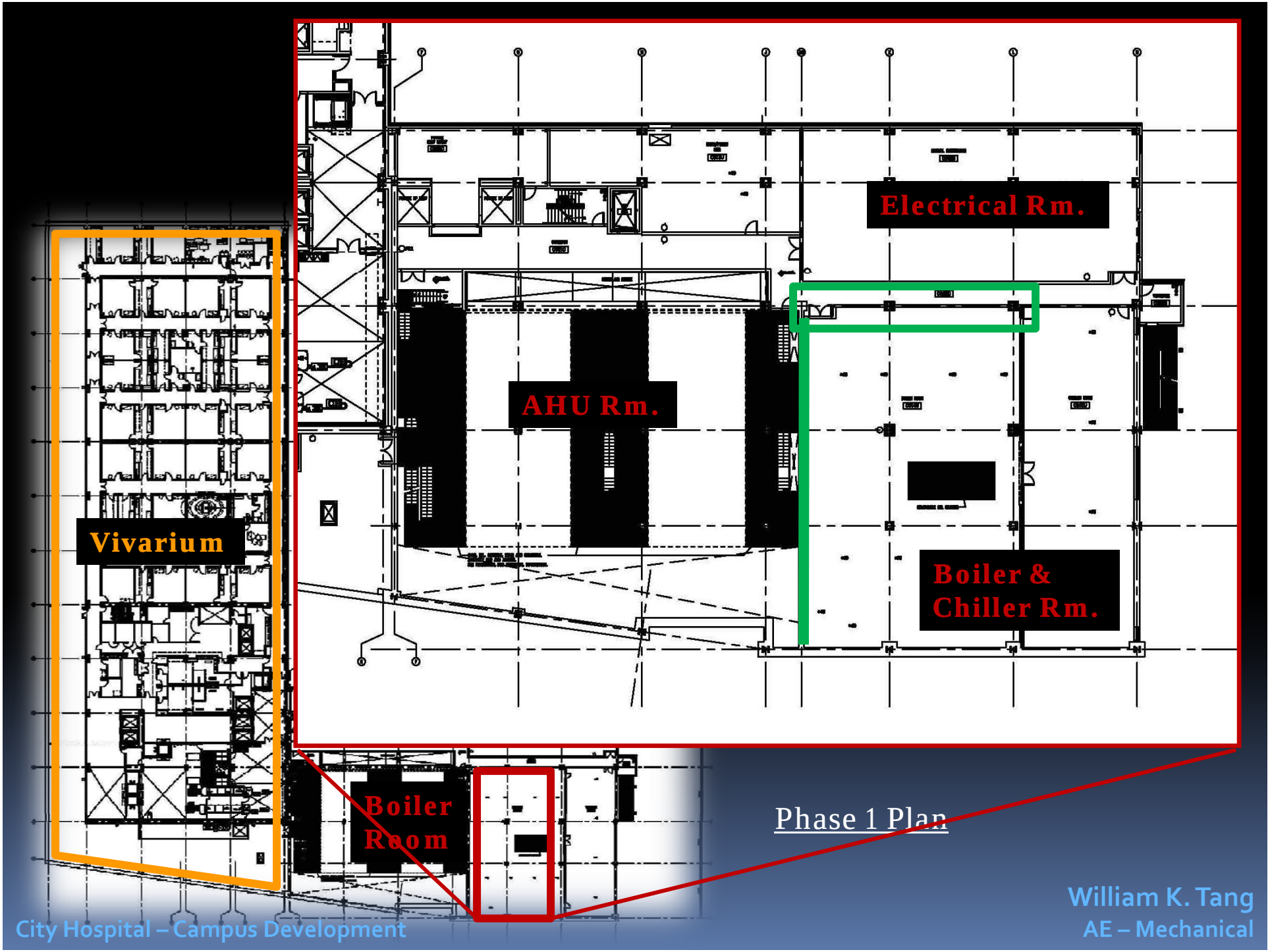

Phase 1 Plan

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Sound Transmission

Transmission Lost Calculation								
	Hz	**125**	**250**	**500**	**1k**	**2k**	**4k**	**Area**
1 – ¾" Steel Door	TL	23	28	36	41	39	44	42
8" CMU wall (painted)	TL	38	38	45	50	52	55	990
Composite Wall	TL_ov	32	dBA					

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Noise Reduction

Noise Reduction Calculation								
	Hz	125	250	500	1k	2k	4k	Area
8" CMU wall (painted)	α	0.1	0.05	0.06	0.07	0.09	0.08	955
	A	95	48	57	67	86	76	
8' Concrete Floor	α	0.01	0.01	0.01	0.02	0.02	0.02	680
	A	7				14	14	
Openings	α	1.				1.0	1.0	180
	A	180	180	180	180	180	180	
Composite Wall	NR	34	dBA					
L2		47	dBA					

L2 < NC laboratory (55 – 58 dBA)

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- 30-year 3 million SF campus development plan
- Alternate design must perform well for P1&2, and the completed campus

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	White Heat Biomedical Research Center	Fred Hutchinson Cancer Research Center	Louis Stoke Laboratories, NIH	Research Laboratories Univ. of California	City Hospital Phase 1&2
Location	Atlanta, GA	Seattle, WA	Bethesda, MD	CA	S.E. PA
Elec. Intensity (kWh/ft2-yr)	63.3	77.0	67.5	79	56.8
Steam Intensity (kBtu/ft-yr)	210	-	-	559	372

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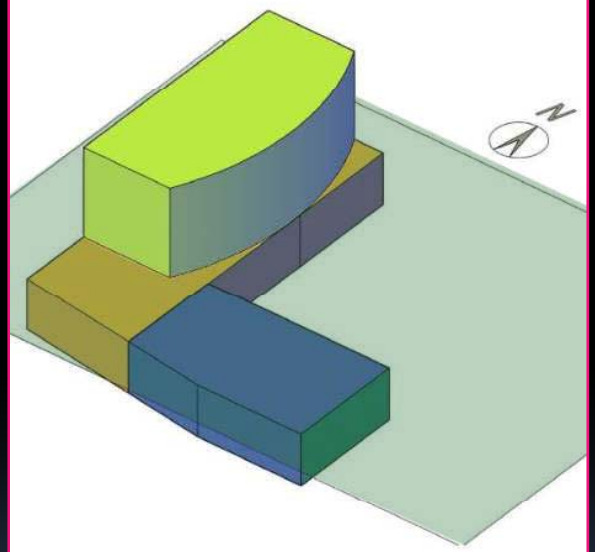
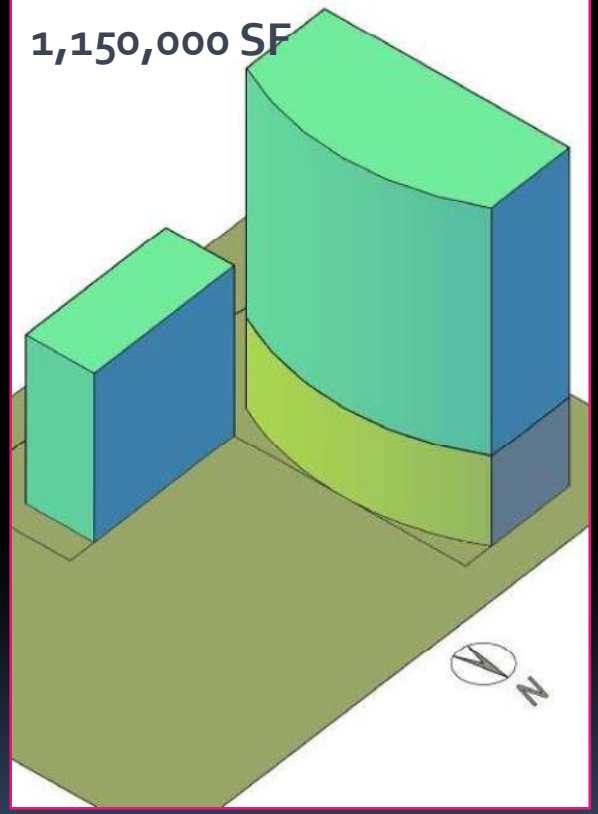
Construction Milestones

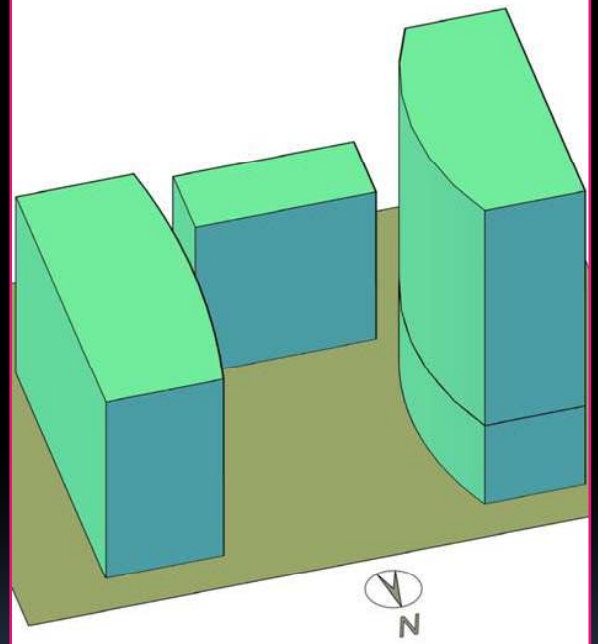
Phase 1&2
420,000 SF



West Towers
1,150,000 SF



Completed Campus
2,000,000 SF



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Estimated Energy Usage

Steam & electricity Demand			
	Phase 1&2	West Tower	Completed Campus
Square Footage	420,000	1,150,000	2,000,000
Peak Steam demand (MMBtu/hr)	31.5	86.0	149.5
Natural Gas Cons. (million therm/yr)	1.25	3.40	5.95
Peak Elec. Demand (kW)	4,800	13,160	22,880
Base Elec. Demand (kW)	1,350	3,685	6,410
Electricity Cons (MWh/yr)	28,650	78,440	136,415

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CHP Equipment Staging

Staging Scenario 1			
	P1&2	West Towers	Completed Campus
1.2 MW CHP	1	2	2
3.5 MW CHP	-	-	1

Staging Scenario 2			
	P1&2	West Towers	Completed Campus
1.2 MW CHP	-	-	-
3.5 MW CHP	-	1	2

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Life Cycle Cost (LCC) Analysis

Analysis Perimeters:

- 20-year period
- 3% discount rate
- NIST fuel cost escalation rate
- capital cost, energy cost, O&M cost
- possible effects of deregulation

Item	Installed Cost	O&M Cost
800 bhp Boiler	$ 380,000	$ 3,560
2,000 bhp Boiler	$ 1,122,000	$ 9,100
1.2 MW CHP	$ 2,067,000	$ 94,000
3.5 MW CHP	$ 4,246,000	$ 209,500

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Possible Effects of Deregulation

- **Baltimore, MD** – consumers experience 75% increase in electricity
- **Pennsylvania** – full deregulation of electric utility on Dec. 30, 2010

4 Possible Scenarios of Deregulation

(1) Normal NIST fuel price escalation
(2) 75% electricity cost increase by 2011, natural gas remain normal
(3) 15% electricity cost increase by 2011, natural gas remain normal
(4) 15% natural gas cost increase by 2009, electricity remain normal

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Discounted Payback Period

Staging Scenario 1 Annual Savings & Pay Back Period ('07 Dollars)						
	P 1&2		West Towers		Completed Campus	
	Savings ($ Mil)	Payback Period	Savings ($ Mil)	Payback Period	Savings ($ Mil)	Payback Period
Normal NIST Escalation	0.01	155	1.2	0.8	2.9	1.6
Elec. Increase 75% ('11)	0.34	6.1	2.3	0.4	5.4	0.8
Elec. Increase 15% ('11)	0.09	23	1.4	0.6	4.2	1.1
NG Increase 15% ('09)	-0.04	-56	1.1	0.8	2.3	2.0

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Discounted Payback Period

Staging Scenario 1 Annual Savings & Pay Back Period ('07 Dollars)						
	P 1&2		West Towers		Completed Campus	
	Savings ($ Mil)	Payback Period	Savings ($ Mil)	Payback Period	Savings ($ Mil)	Payback Period
Normal NIST Escalation	-	-	1.7	1.9	3.4	1.3
Elec. Increase 75% ('11)	-	-	3.4	0.9	6.8	0.7
Elec. Increase 15% ('11)	-	-	2.07	1.5	4.2	1.1
NG Increase 15% ('09)	-	-	1.6	2.0	3.2	1.4

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Alternate System Savings				
	P 1&2	**West Towers**	**Completed Campus**	
Energy Cost ($ Mil)	1.0	2.0	5.8	17 – 27%
CO_2 Reduced (million ton/yr)	6.1	12.3	26.9	60 – 82%
NOx Reduced (ton/yr)	2,570	5,139	11,276	60 – 82%
SO_2 Reduced (ton/yr)	128	255	610	54 – 74%
Car Removed (million)	0.27	0.54	**1.18**	

- population of Philadelphia, PA: 1.5 million (2005)

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- CHP for Phase 1&2 is not economically viable

- CHP w/ larger capacity (Scenario 2) should be install at later construction phases

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Acknowledgements

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AE Students

Brian Ault
Monjia Belizare
Maxwell Chien
Landon Roberts

Family

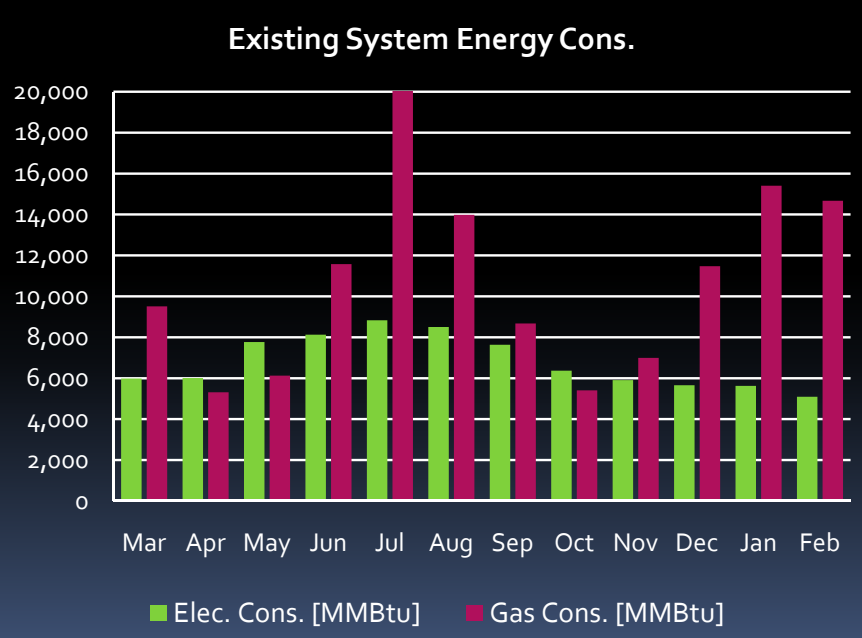
Nikky & Zeus
Parents

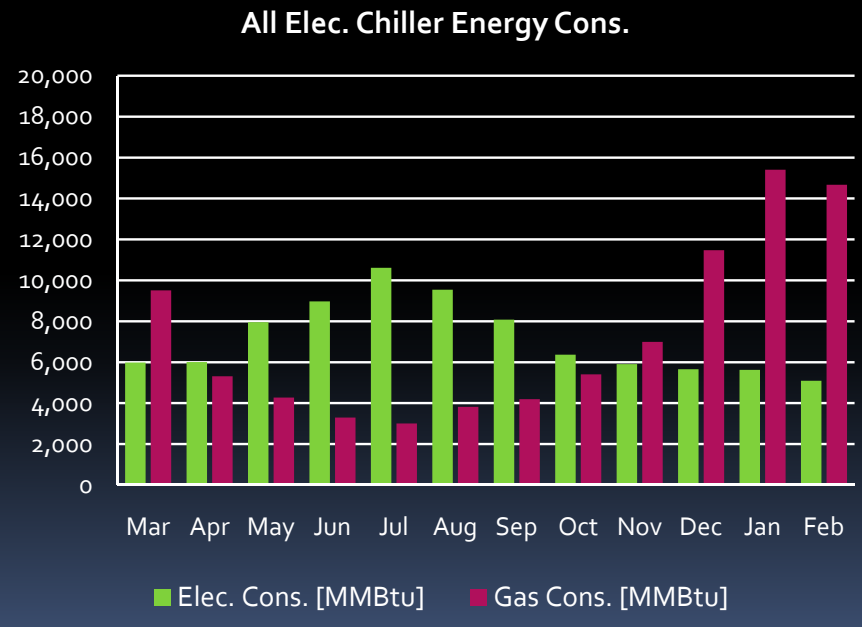
Questions & Comments

Alt. 1: All Elec. Chiller Plant

electric centrifugal
~ 0.598 kW/ton
or 2,041 btuh/ton

steam turbine
~ 11.2 pph steam @ 340°F, 120 psig
or 13,365 btuh/ton



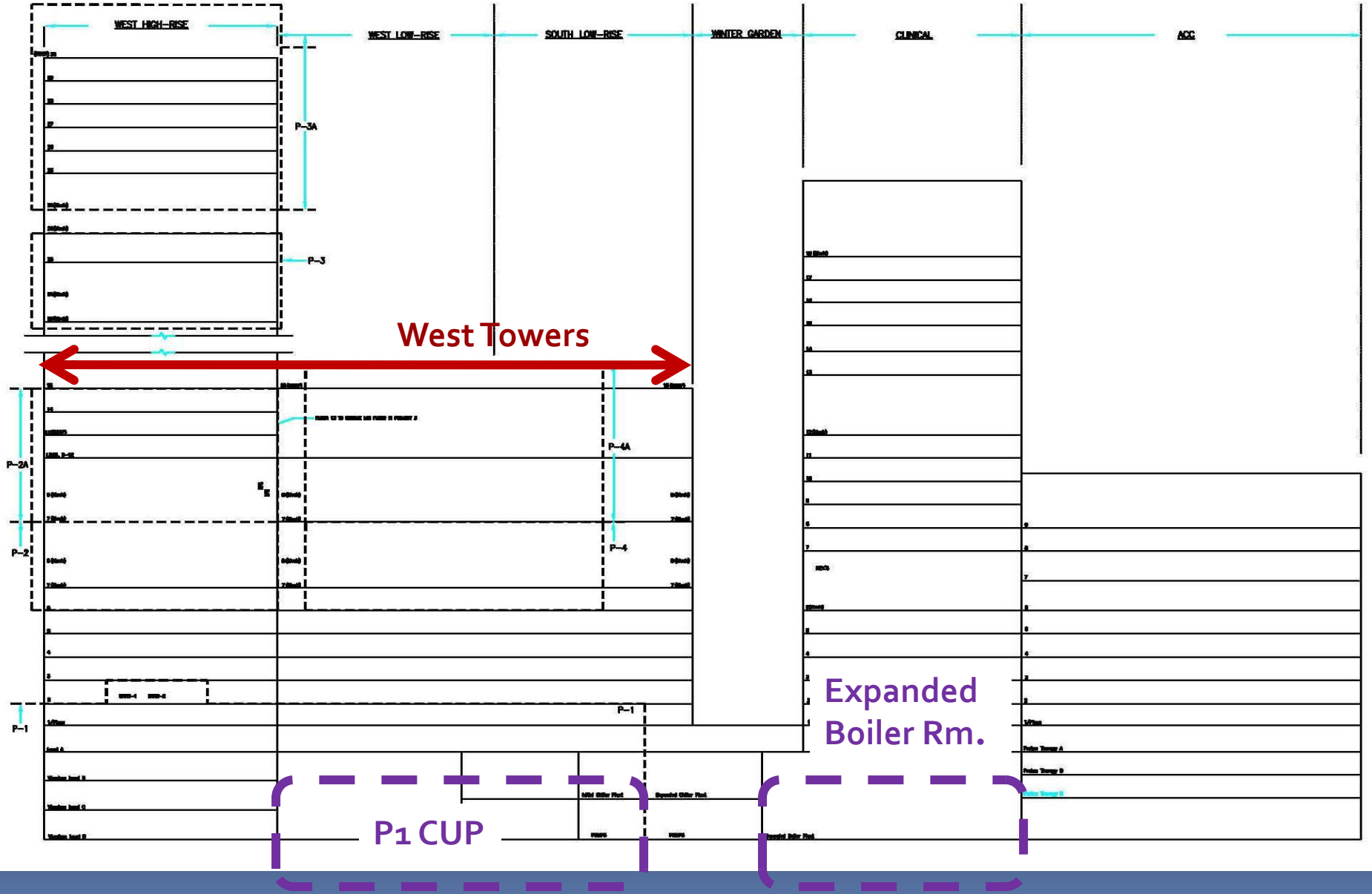


Alt. 1: All Elec. Chiller Plant

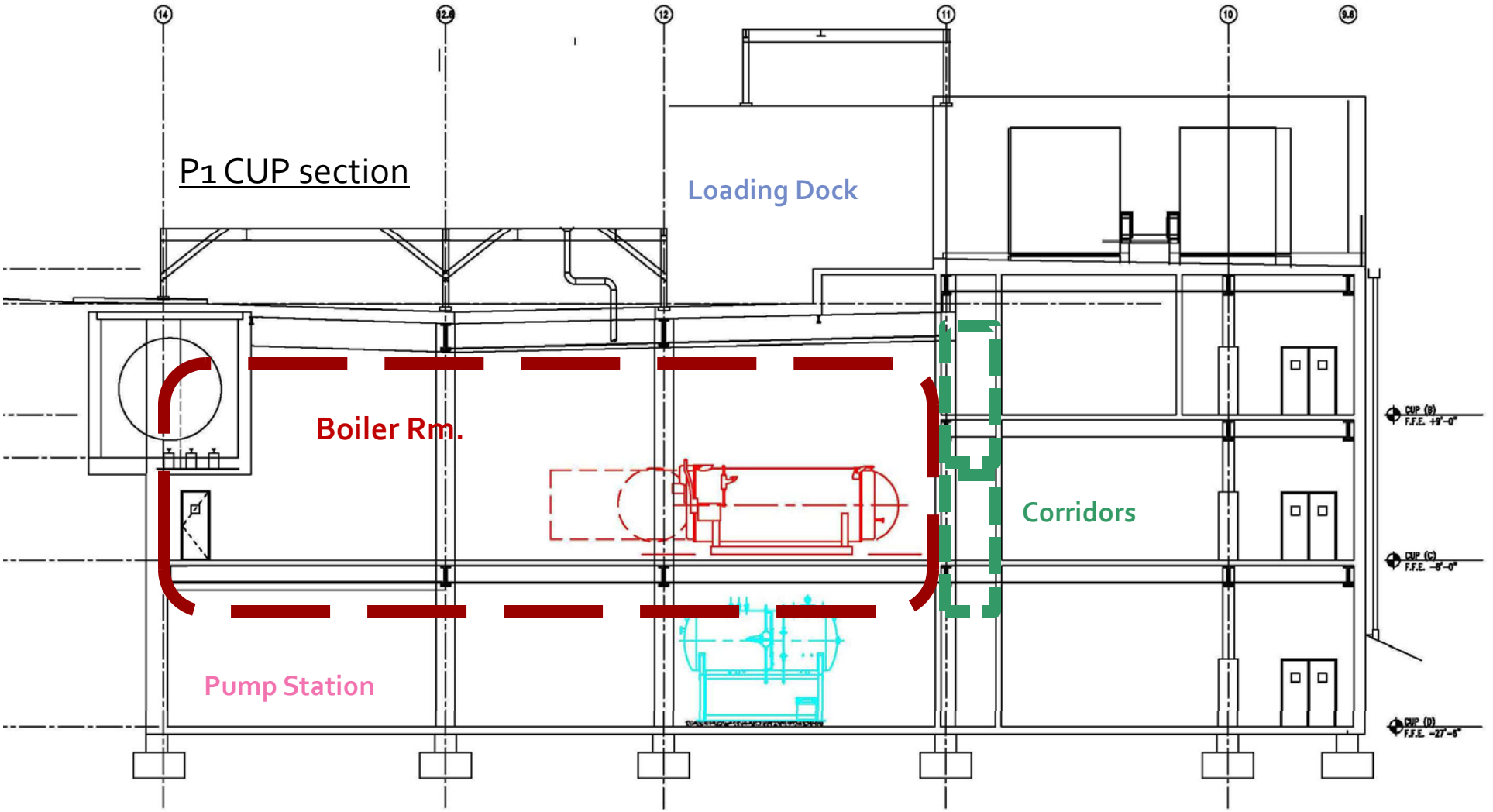
An all electric centrifugal chiller plant

- 84% more efficient
- save $274,000 annually in energy cost (Phase 1&2)
- lack energy source flexibility of existing configuration which is essential for City Hospital

Future Considerations



Acoustic Breadth



Basis for Extrapolation			
Peak Elec.	11		W/ft²
Base Elec.	3		W/ft²
Peak Steam	75		btuh/ft²
	Existing Design	Alt. Design	
Elec. Consumption	57		kWh/ft² - yr
NG Consumption	3.0	3.5 – 4.0	therm/ft² - yr
Cost of Elec.	6.3	2.4 – 4.1	$/ft²
Cost of NG	4.08	5.08 – 5.40	$/ft²
CO_2	17.9	3.2 – 7.2	ton/ft² - yr
Nox	15.0	2.7 – 6.1	lbm/ft² - yr
SO_2	0.7	0.1 – 0.4	lbm/ft² - yr

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	Scenario 1			Scenario 2		
Construction Milestones	Phase 1&2	West Tower	Completed Campus	Phase 1&2	West Tower	Completed Campus
1.2 MW CHP	1	2	2			
3.5 MW CHP			1		1	2
HRSG	1	2	3		1	2
800 BHP Boiler	1	2	1	1	2	1
2000 BHP Boiler			1			1
Backup 800 BHP Boiler	1	1	2	1	1	2
Total MW	1.2	2.4	5.9	0.0	3.5	7.0
CHP MMBtuh	9.6	19.2	42.1	0.0	22.9	45.8
Boiler MMBtuh	32.3	64.5	114.7	32.3	64.5	114.7
Available MMBtuh	41.9	83.7	156.8	32.3	87.4	160.5
Backup Boiler MMBtuh	32.3	32.3	64.5	32.3	32.3	64.5
Boiler MMBtuh	64.5	96.8	179.3	64.5	96.8	179.3
Total MMBtuh	74.1	116.0	378.2	64.5	119.7	385.6
Number of Boilers	2	3	4	2	3	4
Number of Equipments	4	7	10	2	5	8