BUILDING A
WORLD OF
DIFFERENCE

Case Study for Combined Cycle CHP

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Building a world of difference.

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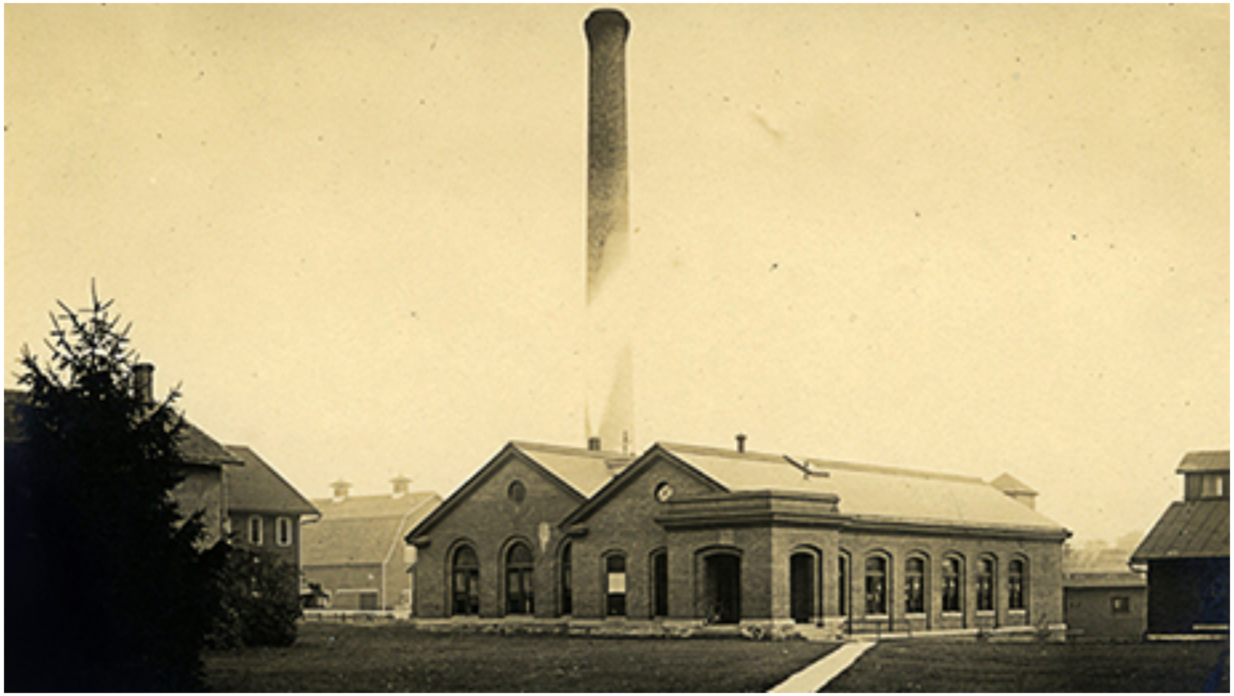
Agenda

1. Overview of Central Heating Plants
2. Need for Power Generation
3. Case Study
4. Apply Combined Cycle
5. Questions

1. Overview of Central Heating Plants - History

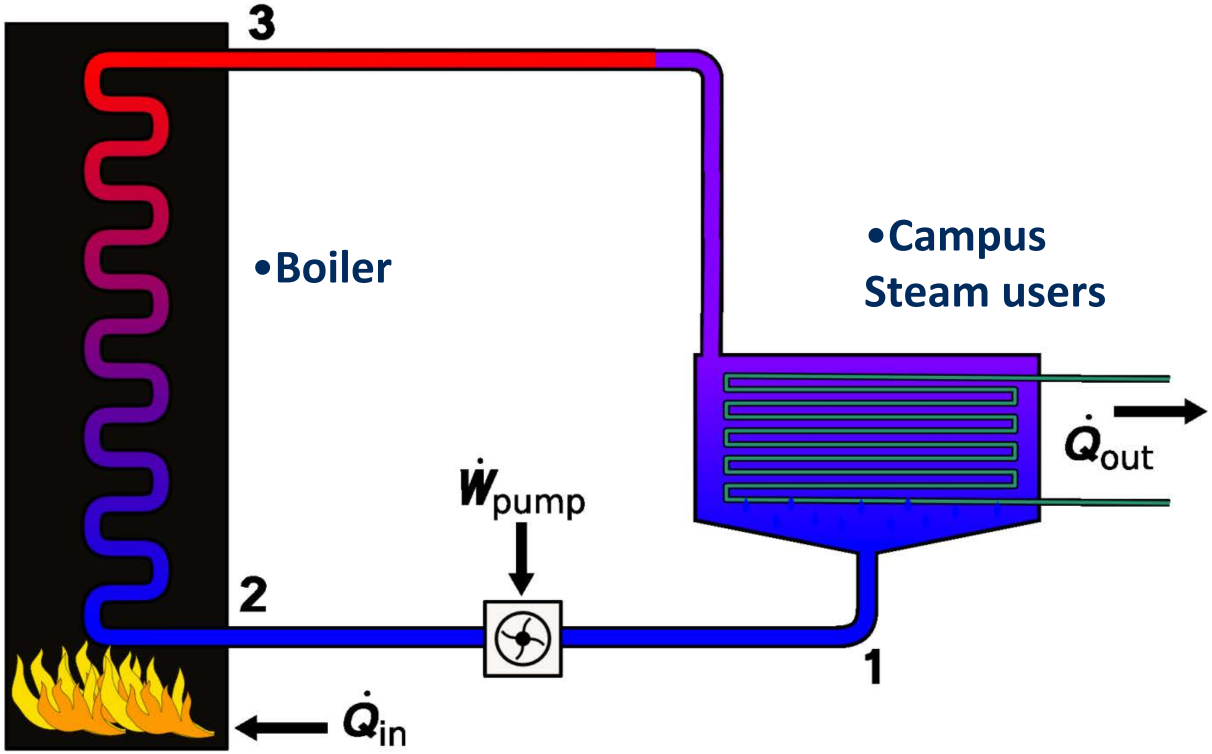
1855, when Michigan State University opened, all of the buildings were heated with wood fireplaces. A series of fires drove leaders to find a better solution to building heating.

1. Overview of Central Heating Plants - History



- 1890, first central heating plant at MSU
- Steam district heating, coal fuel

1. Overview of Central Heating Plants - History



- Boiler

- Campus Steam users

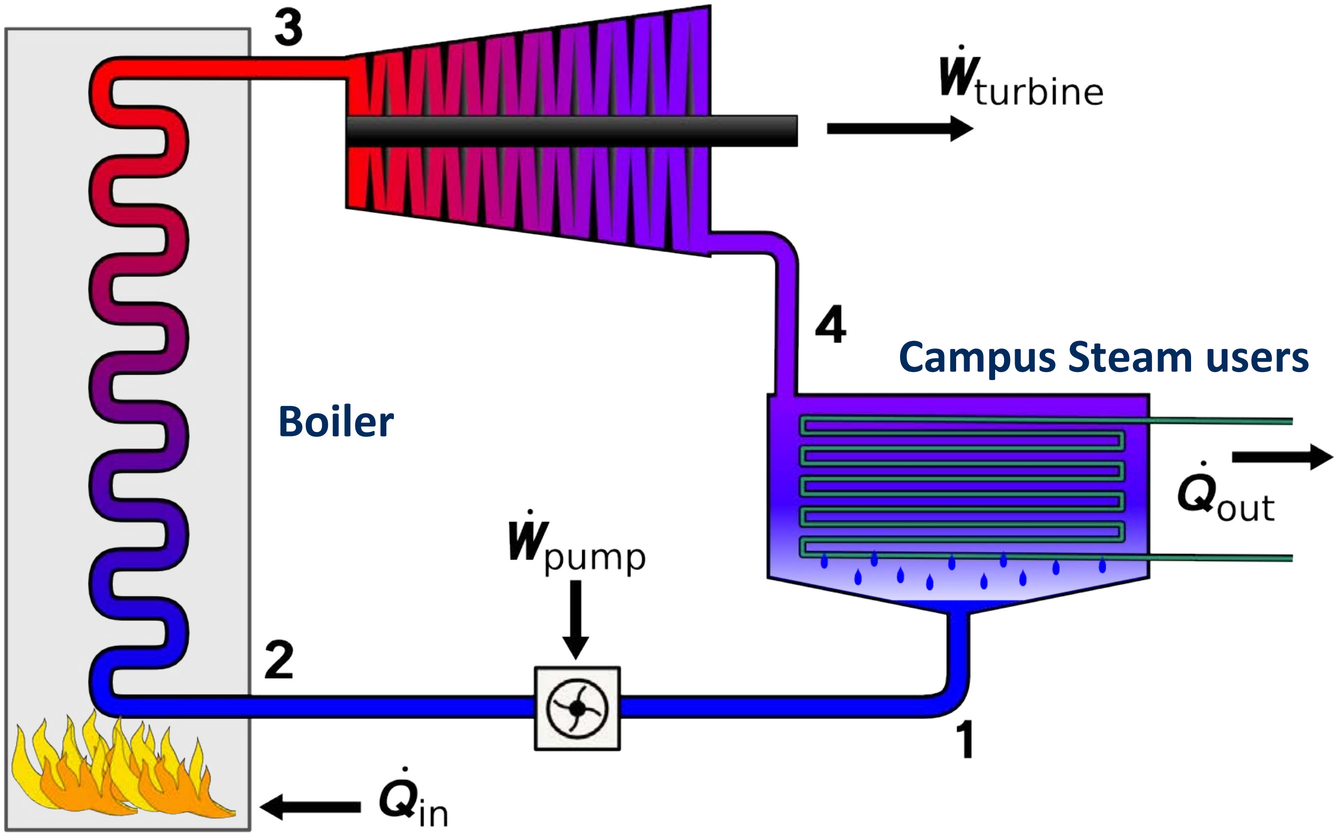
Basic Steam Heating Plant

1. Overview of Central Heating Plants - History

- Rankine thermodynamic cycle converts heat to rotational energy by boosting steam pressure
- 1897, University of Michigan: 75 kilowatt, 220 volt, backpressure electrical generator
- 1940, Cornell: 200 psi superheated steam, 300 kW backpressure turbines
- Coal fuel

Cogeneration, or Combined Heat & Power (CHP)

1. Overview of Central Heating Plants - History



Rankine Thermodynamic Cycle

1. Overview of Central Heating Plants - History

Low pressure Rankine Cycle serves low electric load and high heating load

- First produce steam, the primary interest
- Second use steam to produce power on the way to serving heating loads

More than 20 lbs steam per kilowatt hour of electricity produced

1. Overview of Central Heating Plants - History

Primary Purpose: Heat

- Electric loads: lights, radios, small fans
- Heat loads: poorly insulated, drafty buildings, domestic hot water

Low Electric Load, High Heating Load

1. Overview of Central Heating Plants - History

Second half of 20th century:
enter modern conveniences

- Television, clothes dryers, vacuum sweepers, air conditioners, toasters, electric stoves, microwave ovens, computers, and multiples of all these

- Electric loads rising

1. Overview of Central Heating Plants - History

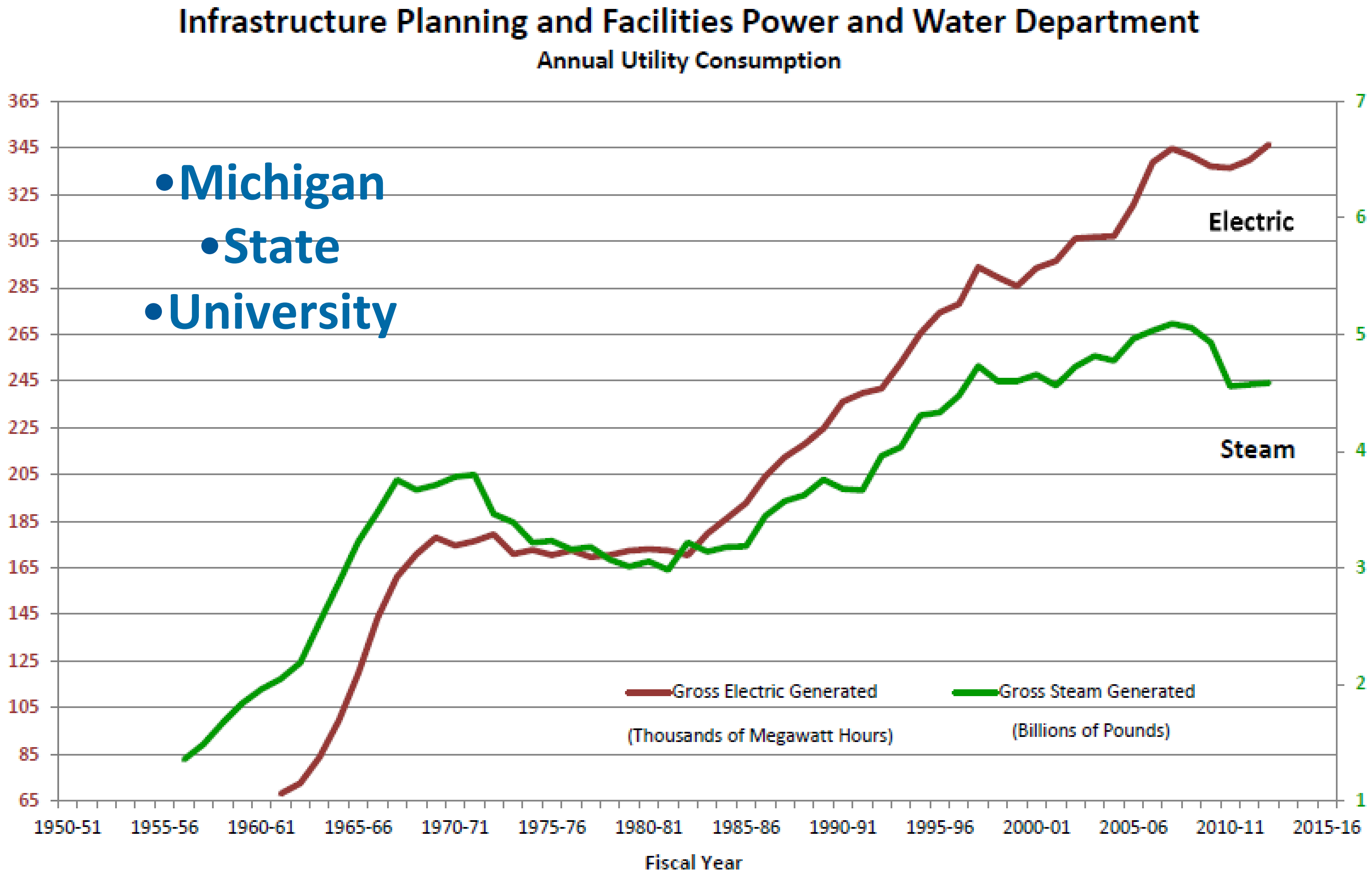
Second half of 20th century:
Energy Crisis of 1974

- Building design: thermal insulation, double pane windows, weather stripping, ventilation heat recovery, energy efficiency standards
- Direct fired natural gas heat in industry
- Steam heating loads dropping

Need: More Power Generation, Less Steam

1. Overview of Central Heating Plants - History

- Michigan
  - State
- University



Infrastructure Planning and Facilities Power and Water Department

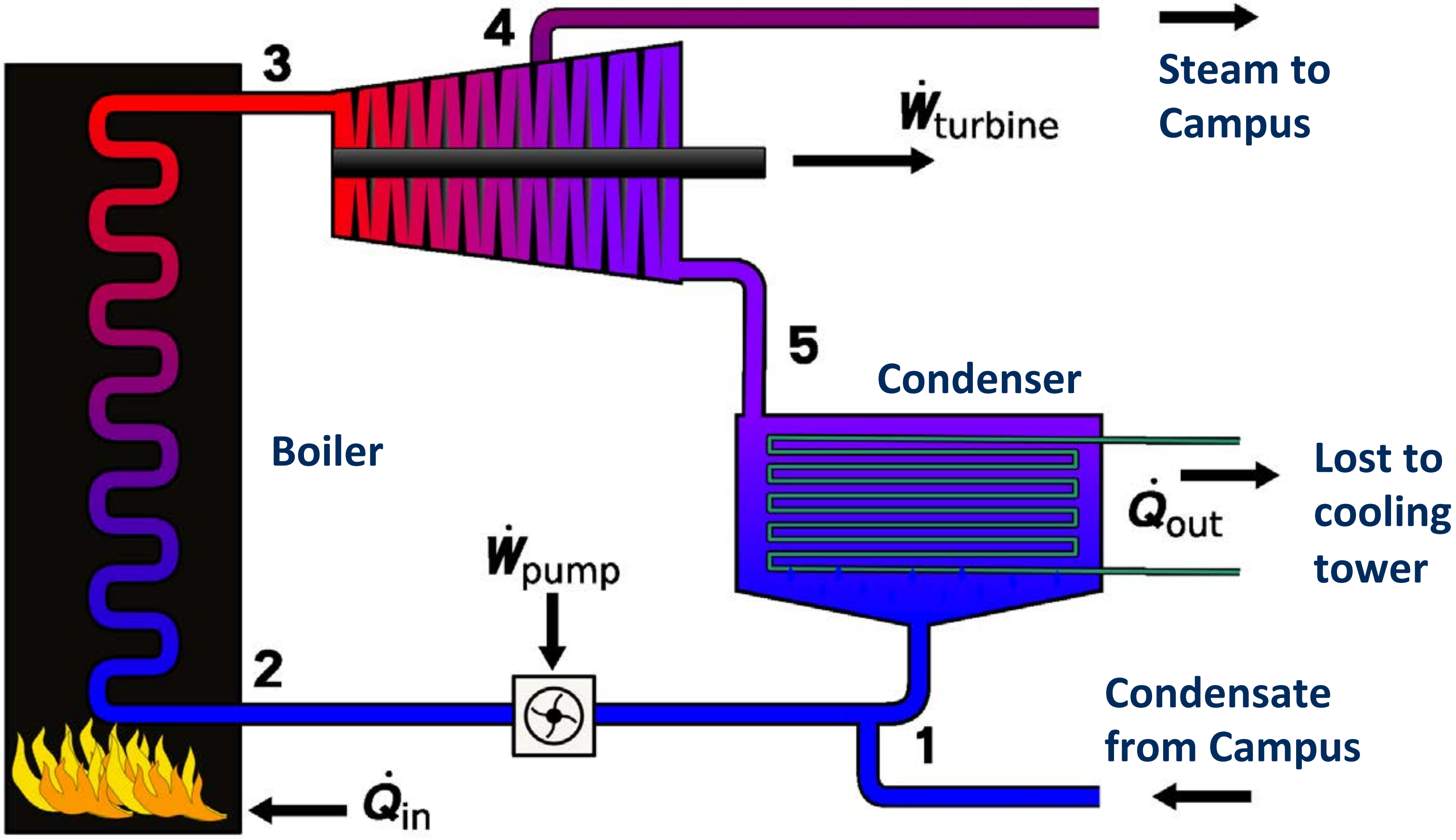
Annual Utility Consumption

2. Need for Power Generation

Michigan State University's
T.B. Simon Power Plant

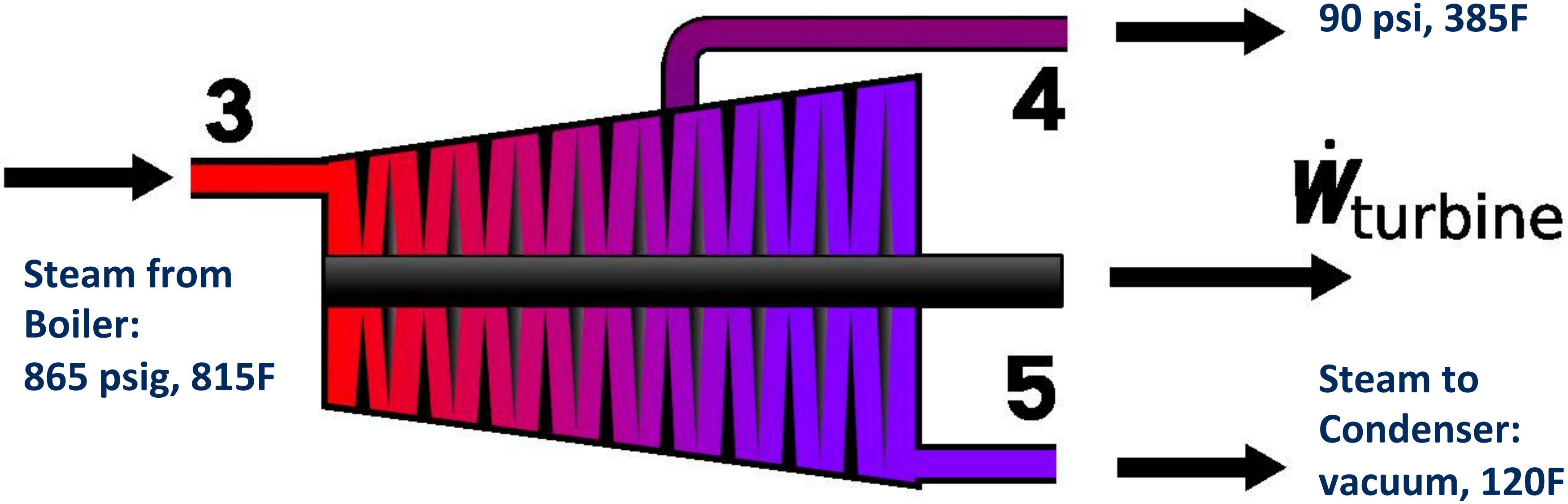
- Built in 1965
- Pulverized coal boilers: 865 psig, 815F superheated steam
- Condensing steam turbines with extraction
- Expanded with campus growth to serve all loads

2. Need for Power Generation



Condensing Steam Turbine with Extraction

2. Need for Power Generation



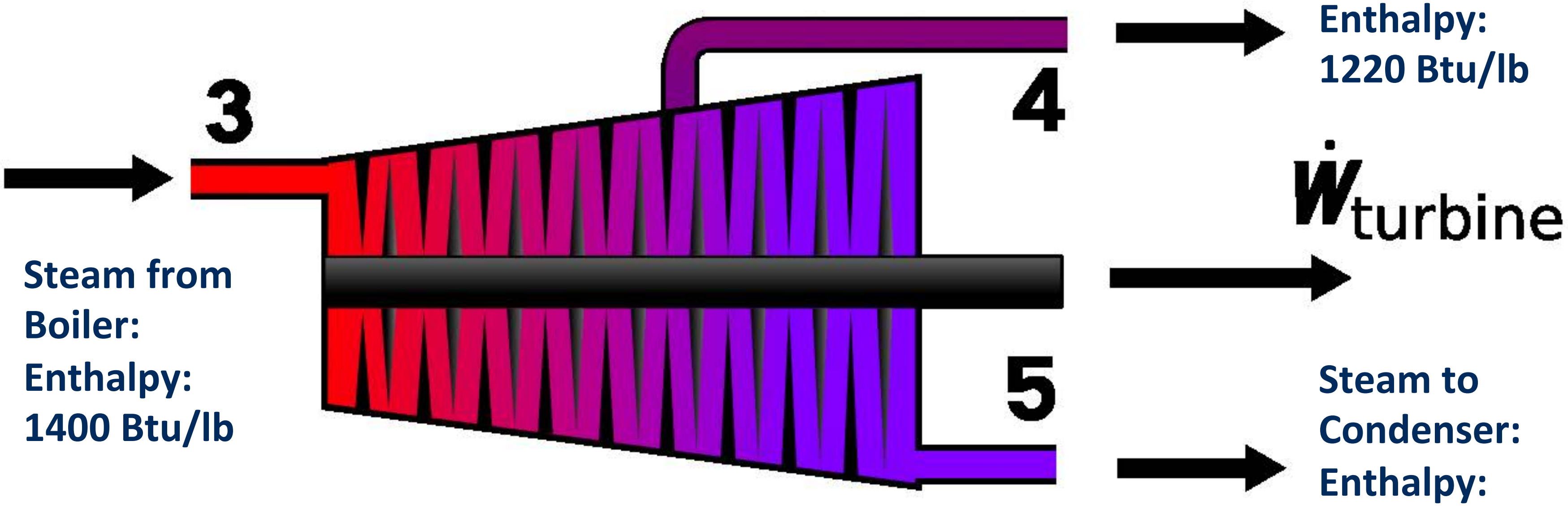
Steam to
Campus:
90 psi, 385F

Steam from
Boiler:
865 psig, 815F

Steam to
Condenser:
vacuum, 120F

Condensing Steam Turbine with Extraction

2. Need for Power Generation



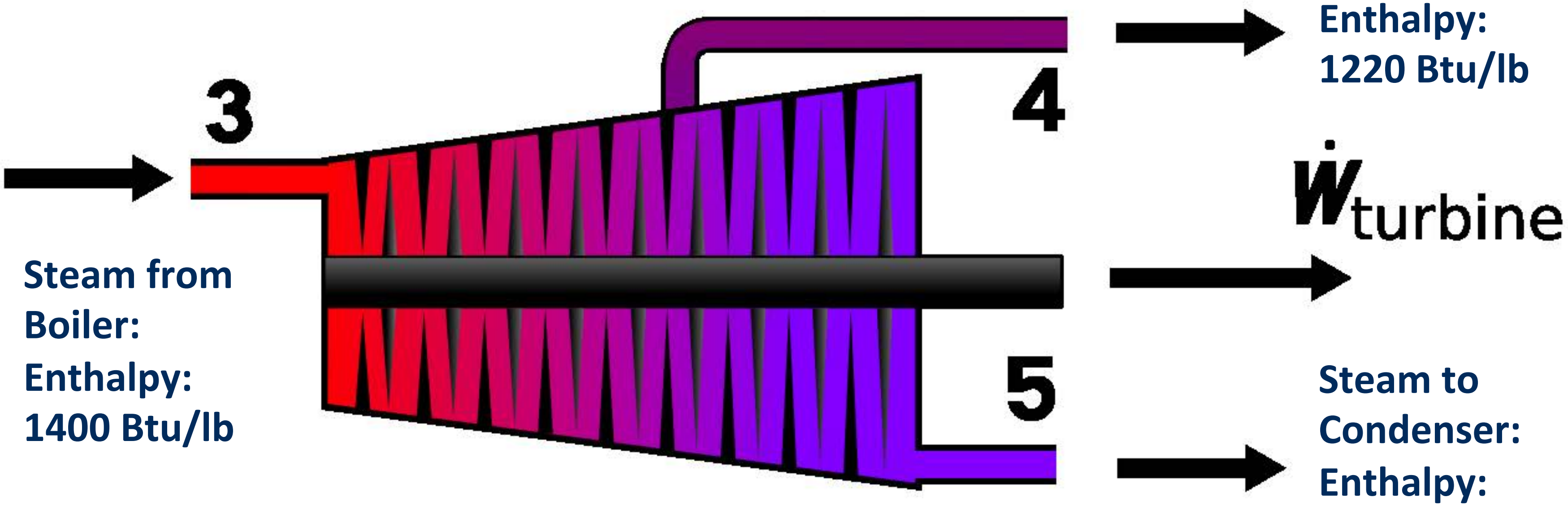
Steam from
Boiler:
Enthalpy:
1400 Btu/lb

Steam to
Campus:
Enthalpy:
1220 Btu/lb

Steam to
Condenser:
Enthalpy:
1040 Btu/lb

Condensing Steam Turbine Performance

2. Need for Power Generation



Steam from Boiler:
Enthalpy:
1400 Btu/lb

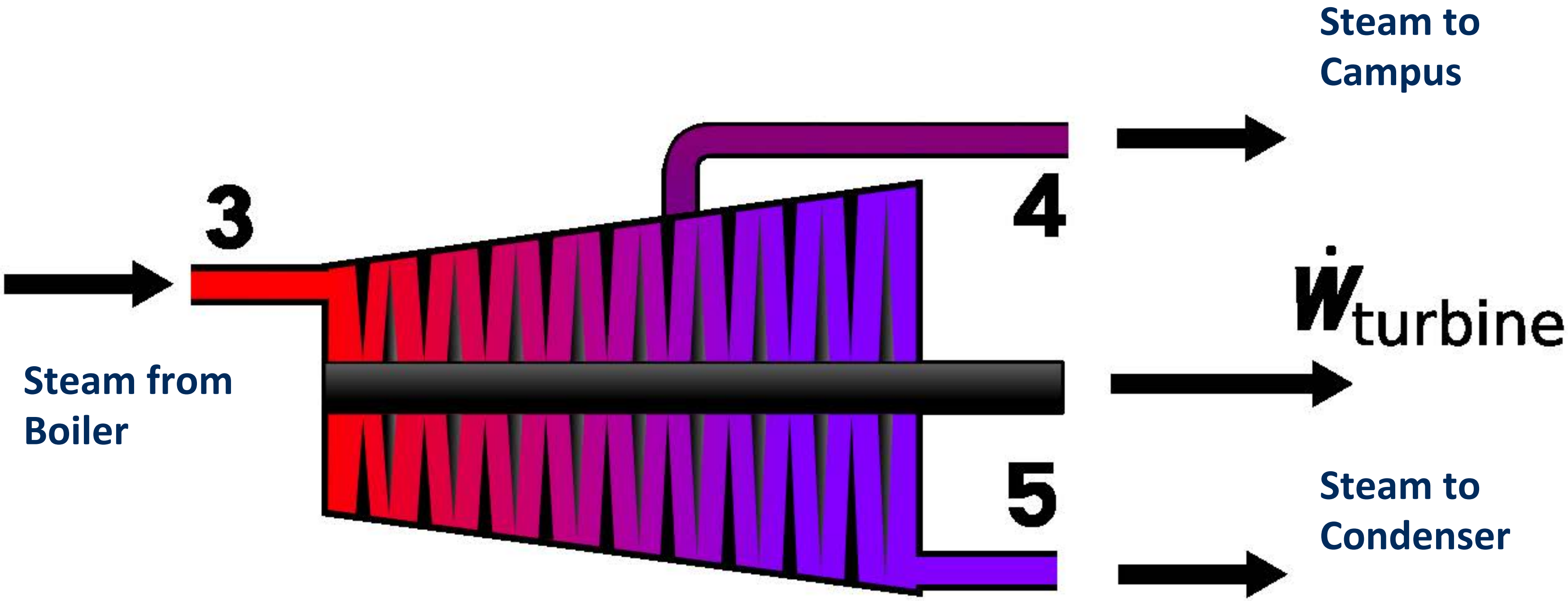
Steam to Campus:
Enthalpy:
1220 Btu/lb

Steam to Condenser:
Enthalpy:
1040 Btu/lb

$$\text{lbs stm per kWhr} = \frac{3412 \text{ Btu/kWhr}}{(\text{enthalpy in} - \text{enthalpy out}) \text{ Btu/lb} \times \text{turb eff}}$$

Condensing Steam Turbine Performance

2. Need for Power Generation



lbs steam per kWhr, point 3 to 4 = 20 lbs steam / kWhr

lbs steam per kWhr, point 3 to 5 = 10 lbs steam / kWhr

2. Need for Power Generation

Only 10 lbs steam per kilowatt hour of electricity produced through condenser, but

- The heat content of all of the 10 lbs of condenser steam per kWhr is delivered to the cooling tower
- Enthalpy diff of that steam minus condensate return, at 950 Btu/lb, is lost to atmosphere

3. Case Study

Michigan State University's T.B. Simon Power Plant

Total plant net outputs in FY 2012:

- Total steam produced: 4,582,000 klbs
- Steam used on campus: 2,222,000 klbs
- Generated power to campus: 235,000 MWhr
- Clg tower condensed steam: 958,000 klbs

3. Case Study

Michigan State University's
T.B. Simon Power Plant

Steam Turbine Conditions in FY 2012:

- Steam turbine performance: 15 lbs steam/kWhr
- Actual Campus Energy Mix:

$$\frac{2{,}222{,}000 \text{ klbs}}{235{,}000 \text{ MWhr}} = 9.5 \text{ lbs / kWhr}$$

3. Case Study

Michigan State University’s
T.B. Simon Power Plant

Total plant net thermal efficiency in FY 2012:

$$Eff = \frac{235{,}000\ \text{MWhrs} \times 3412\ \text{Btu/kWhr} + 2{,}434{,}000\ \text{MMBtu}}{5{,}794{,}000\ \text{MMBtu}}$$

$$= 56\%$$

3. Case Study

Energy Outputs Accounting FY 2012, in MMBtu:

- Campus electricity: 802,000 = 16%
- Plant electricity: 247,000 = 5%
- Campus steam: 2,434,000 = 47%
- Plant steam: 650,000 = 13%
- Clg tower steam: 980,000 = 19%

Total: 5,113,000 = 100%

3. Case Study

In order to improve efficiency, consider decreasing:

	MMBtu		
• Plant electricity:	247,000	=	5%
• Plant steam:	650,000	=	13%
• Clg tower steam:	980,000	=	19%
Total:	1,877,000	=	37%

3. Case Study

Consider a Combined Cycle CHP

Thermodynamic reasons:

- CTG makes power without any steam
- Less steam means less DA and feedwater heating steam, less water treatment
- Less steam power means less cooling tower
- Eliminates fans, pulverizers, coal handling, ash handling loads

4. Apply Combined Cycle

Major Equipment

- Combustion Turbine Generator
- Heat Recovery Steam Generator
- Steam Turbine Generator
- Fuel gas compressor, if needed

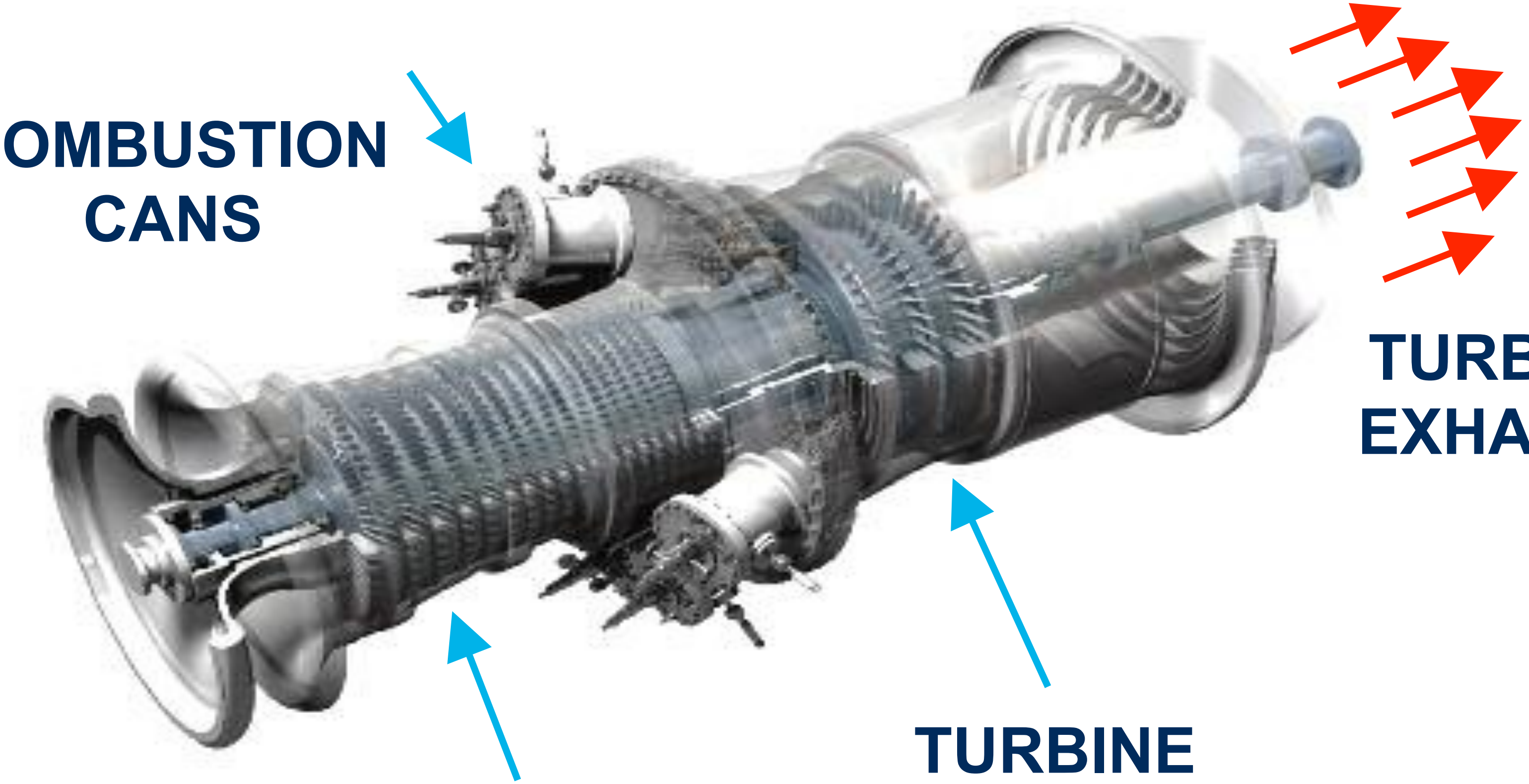
4. Apply Combined Cycle

Cycle Sequence

- First, generate electricity in combustion turbine generator
- Second, generate steam in heat recovery steam generator
- Third, generate more electricity in steam turbine generator
- Fourth, send steam to campus

4. Apply Combined Cycle

Combustion Turbine Generator



COMBUSTION CANS

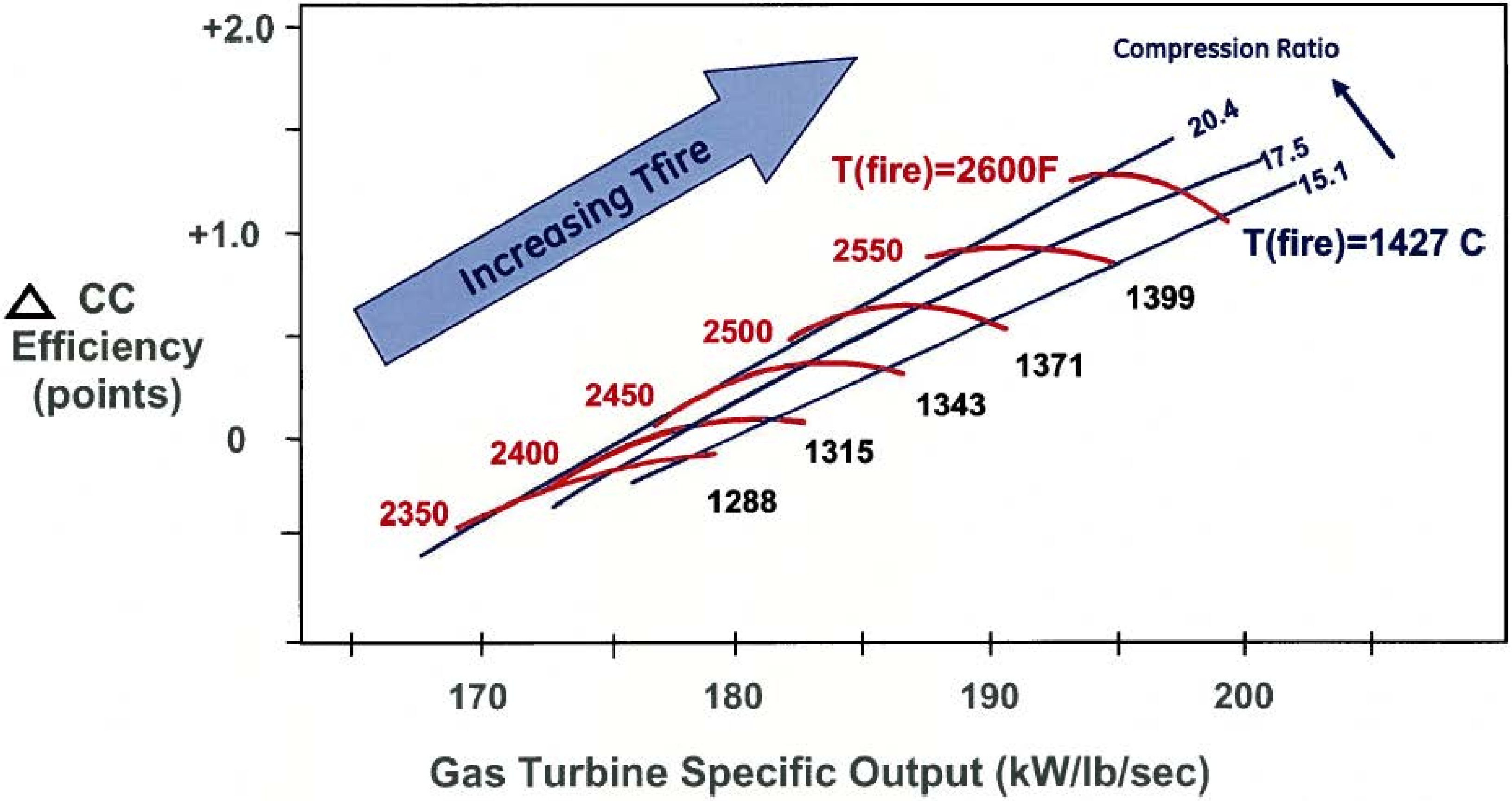
TURBINE EXHAUST

TURBINE SECTION

COMPRESSOR SECTION

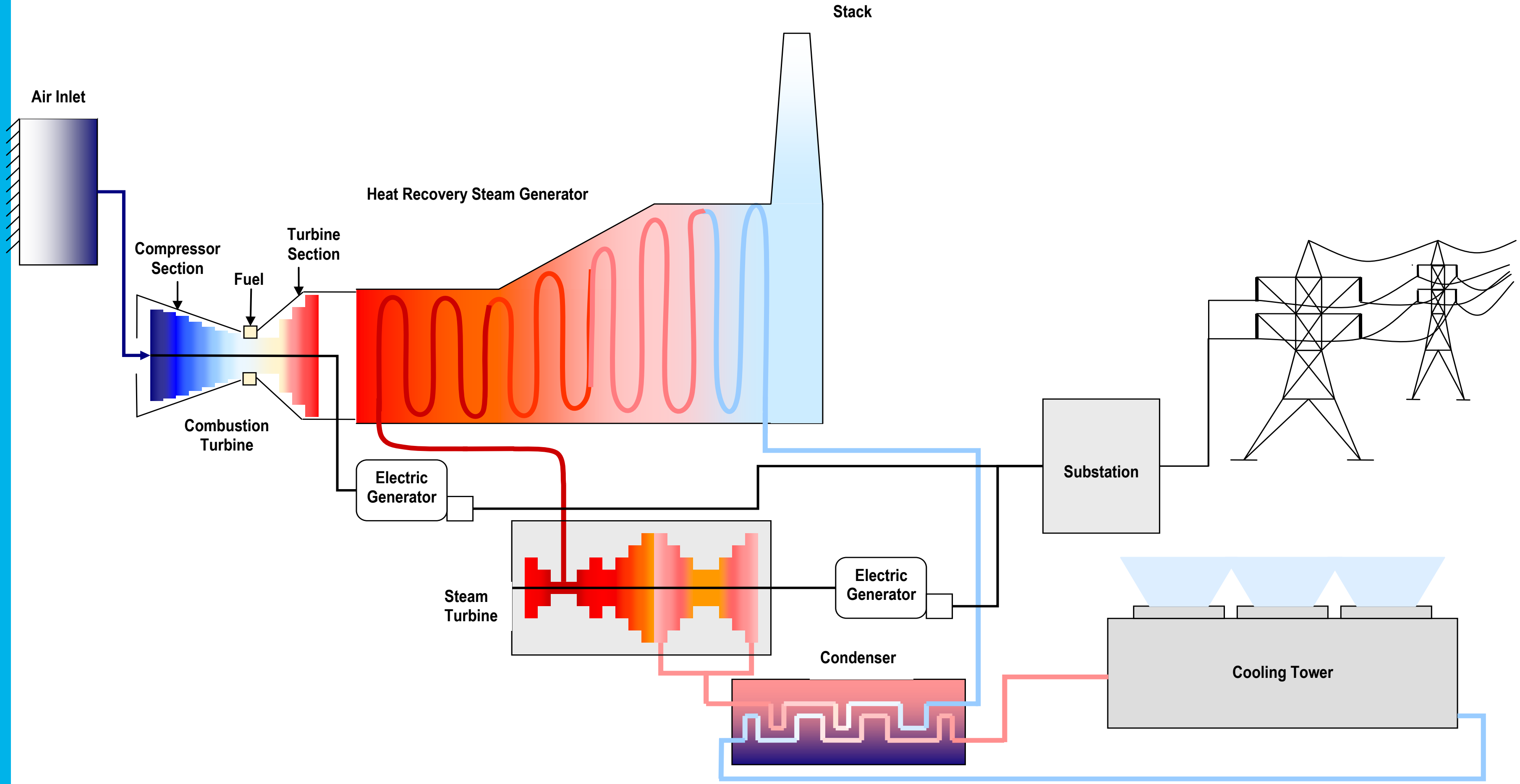
4. Apply Combined Cycle

Combustion Turbine Inlet Temperature (Tfire)



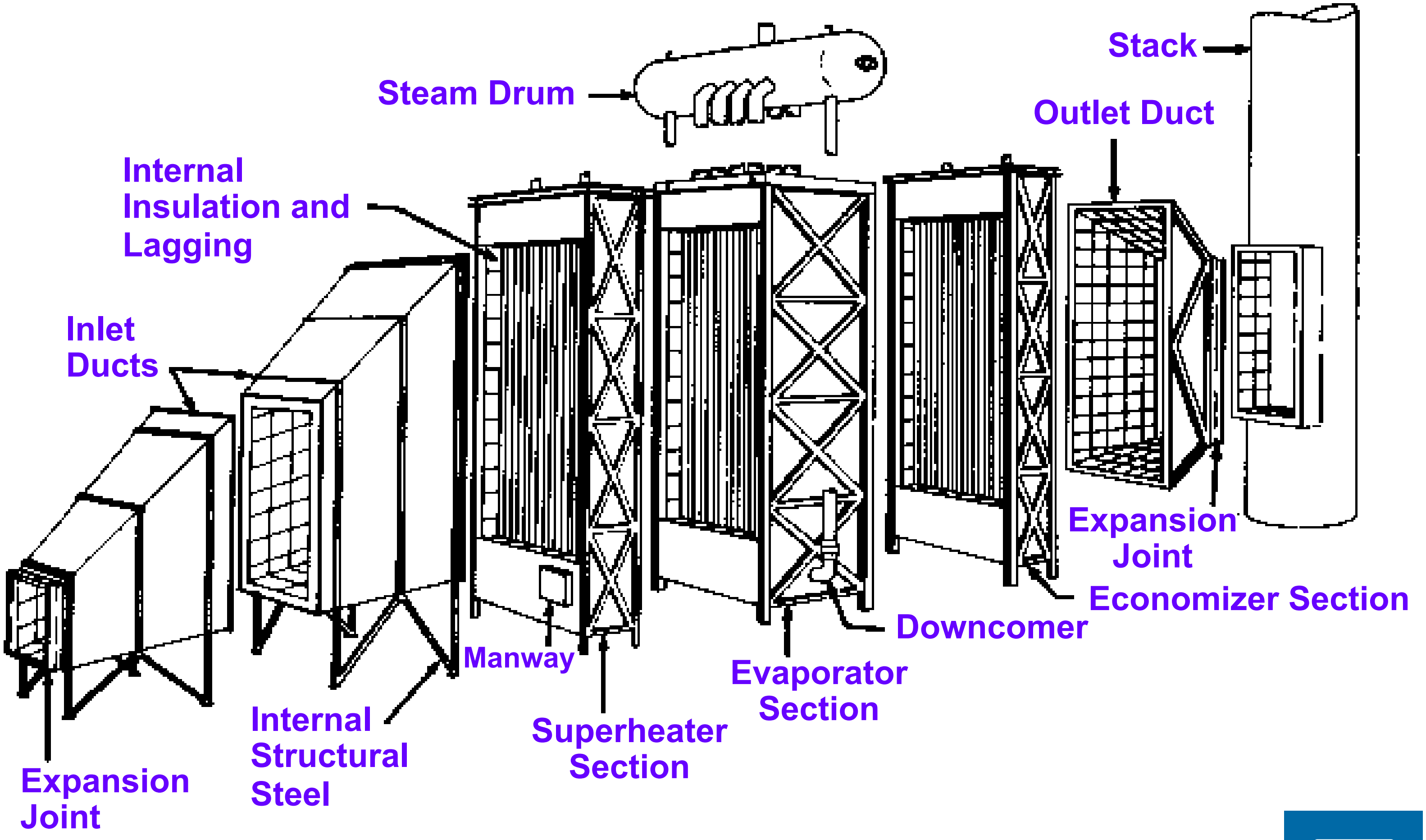
4. Apply Combined Cycle

Combined Cycle Process Flow



4. Apply Combined Cycle

- Heat Recovery Steam Generator (HRSG)



4. Apply Combined Cycle

Deaerating Condenser or Pressurized Deaerator

- Combined cycle designs do not use regenerative feed water heaters
- Condensate supplied to the HRSG should be as cold as possible.
- Recirculation of hot condensate, already heated by the HRSG, will typically be used to raise the condensate temperature to 140 F before it enters the HRSG
- The HRSG can incorporate an integral pressurized deaerator onto the low pressure steam drum
- Alternatively, if there is minimal cycle makeup flow, a deaerating condenser is adequate.
- The boiler feed pumps take suction from the low pressure drum in both configurations

4. Apply Combined Cycle

Michigan State University's
T.B. Simon Power Plant

<u>Apply a Solar Titan 250 to the FY 2012 data</u>:

- Steam used on campus: 2,222,000 klbs
- Generated power to campus: 235,000 MWhr
- Campus energy mix: <u>9.5 lbs steam/kWhr</u>,

. . . and falling

4. Apply Combined Cycle

Michigan State University's
T.B. Simon Power Plant

Apply a Solar Titan 250 to the FY 2012 data:

- Steam used on campus: 2,222,000 klbs
- Generated power to campus: 235,000 MWhr
- Campus energy mix: 9.5 lbs steam/kWhr,

. . . *and falling*

4. Apply Combined Cycle

Solar Titan 250 Performance

- Power gross output: 20,330 kW
- Power net output: 19,010 kW
- Aux load: 1,320 kW
- Fuel input (NG HHV): 201,620 kBtu/hr
- Net Power Efficiency: 32.2%
- Net Power Heat Rate: 10,600 Btu/kWhr

4. Apply Combined Cycle

Heat Recovery Steam Generator

- Unfired steam output: 75,120 lb/hr
- Unfired fuel input (NG HHV): 24,710 kBtu/hr
- Unfired Steam turbine output: 3,760 kW
- Fired steam output: 157,200 lb/hr
- Fired fuel input (NG HHV): 125,650 kBtu/hr
- Fired Steam turbine output: 7,860 kW

4. Apply Combined Cycle

Combined Cycle Overall Performance

- Unfired power net output: 22,770 kW
- Unfired fuel input (NG HHV): 226,330 kBtu/hr
- Unfired campus steam: 82,300 kBtu/hr
- Fired power net output: 26,730 kW
- Fired fuel input (NG HHV): 327,260 kBtu/hr
- Fired campus steam: 172,220 kBtu/hr

4. Apply Combined Cycle

Unfired Combined Cycle Overall Performance

$$Eff = \frac{22{,}770\ kW\ \ x\ \ 3.412\ kBtu/kWhr\ +\ 82{,}300\ kBtu/hr}{226{,}330\ MMBtu} = 70\%$$

$$Steam\ Rate = \frac{75{,}120\ lb/hr}{22{,}770\ kW} = 3.3\ lb\ steam\ /\ kWhr$$

4. Apply Combined Cycle

Fired Combined Cycle Overall Performance

$$Eff = \frac{\bullet 26{,}730\ kW\ \ x\ \ 3.412\ kBtu/kWhr\ +\ 172{,}220\ kBtu/hr}{327{,}260\ MMBtu} = 80\%$$

$$Steam\ Rate = \frac{157{,}200\ lb/hr}{26{,}730\ kW} = 5.9\ lb\ steam\ /\ kWhr$$

4. Apply Combined Cycle

Conclusion

If you have CHP thermal-to-electric loads that are less than 15 lbs steam per kWhr of electricity, consider what a combustion turbine combined cycle CHP system could do to better balance your coincident energy outputs to your demands.

Questions?

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