IAGT SYMPOSIUM 17

IAGT Industrial Application of Gas Turbines

www.iagtcommittee.com

October 23rd - 25th, 2017, Banff, Alberta

Day 1 Training Session #2

Cogeneration & Power Plant Basics

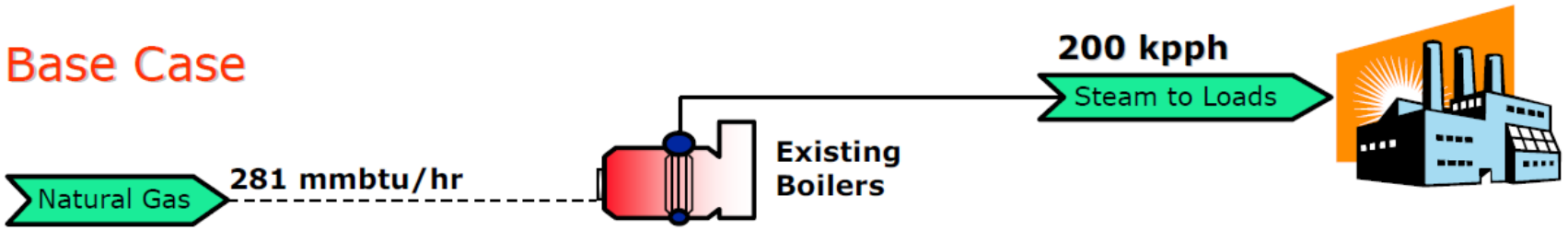
Jim Noordermeer
Noord Power Consulting Inc.

An introduction to the basics of cogeneration and power plants, utilizing gas turbines and related equipment

Presented at the 2017 Symposium on Industrial Application of Gas Turbines (IAGT)
Banff, Alberta, Canada - October 2017
The IAGT Committee shall not be responsible for statements or opinions advanced in technical papers or in symposium or meeting discussions.

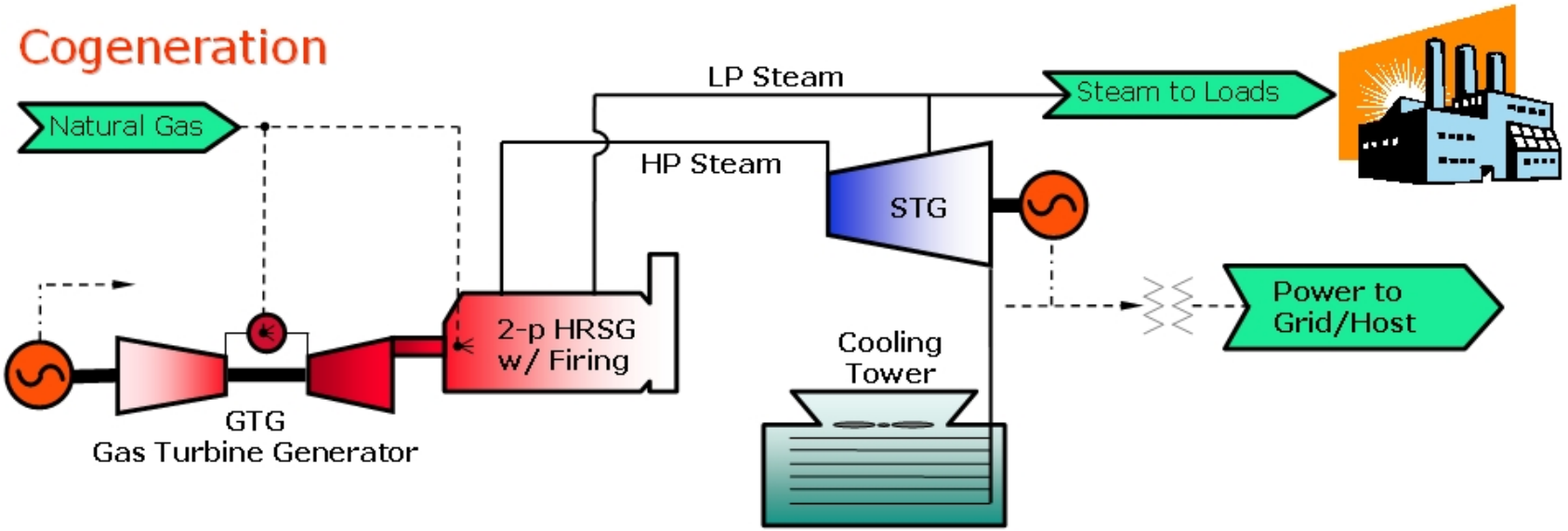
SHP / SEPARATE HEAT-AND-POWER:

"On-site heat/cooling production for industrial processes or space heating / cooling, and electricity from central large-scale power plants"



CHP / COGENERATION:

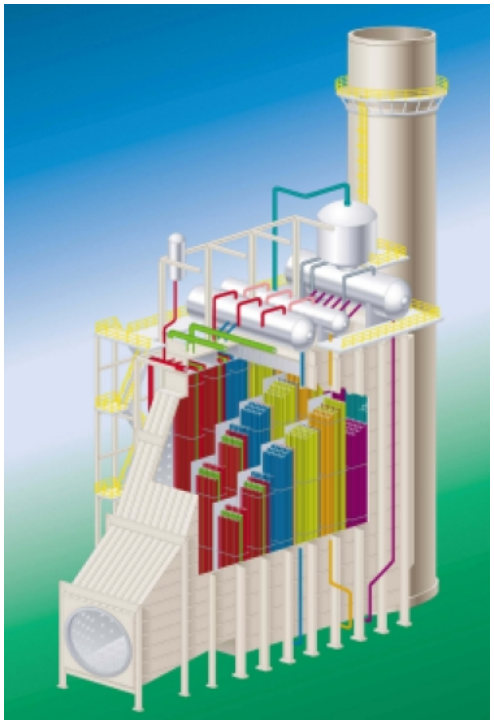
"The simultaneous production of two or more forms of useful energy (e.g. heat / cooling and electricity) from a single fuel source, usually on-site or nearby"

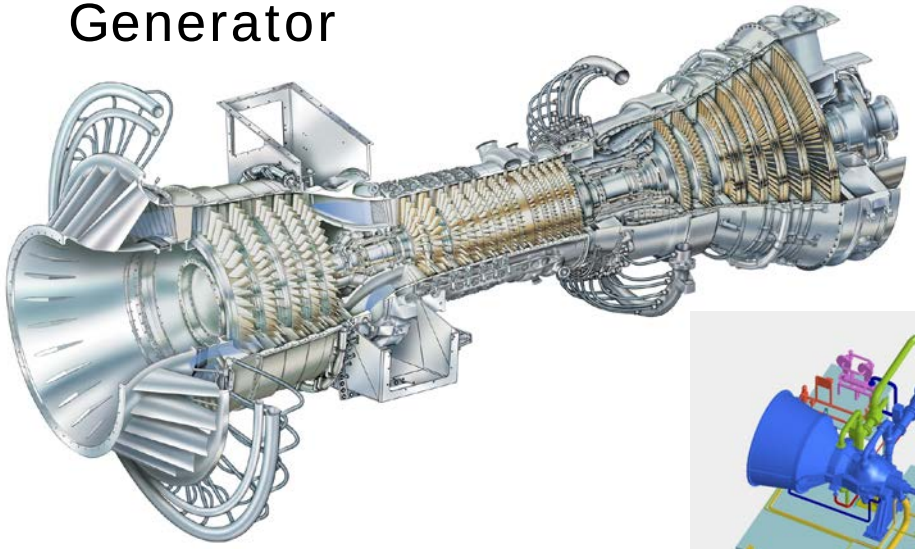


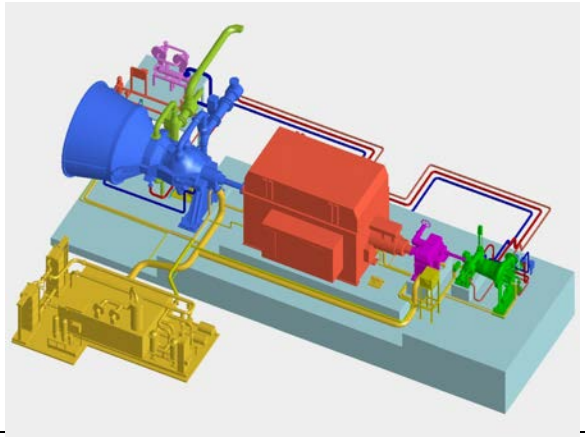
MAJOR EQUIPMENT

Usually associated with Cogeneration / CHP cycles

- Steam generator or boiler
- Steam turbine generator (STG)
- Gas turbine generator (GTG)
- Heat recovery steam generator (HRSG)
- Reciprocating Gas, Dual-Fuel or Diesel Engine Generator



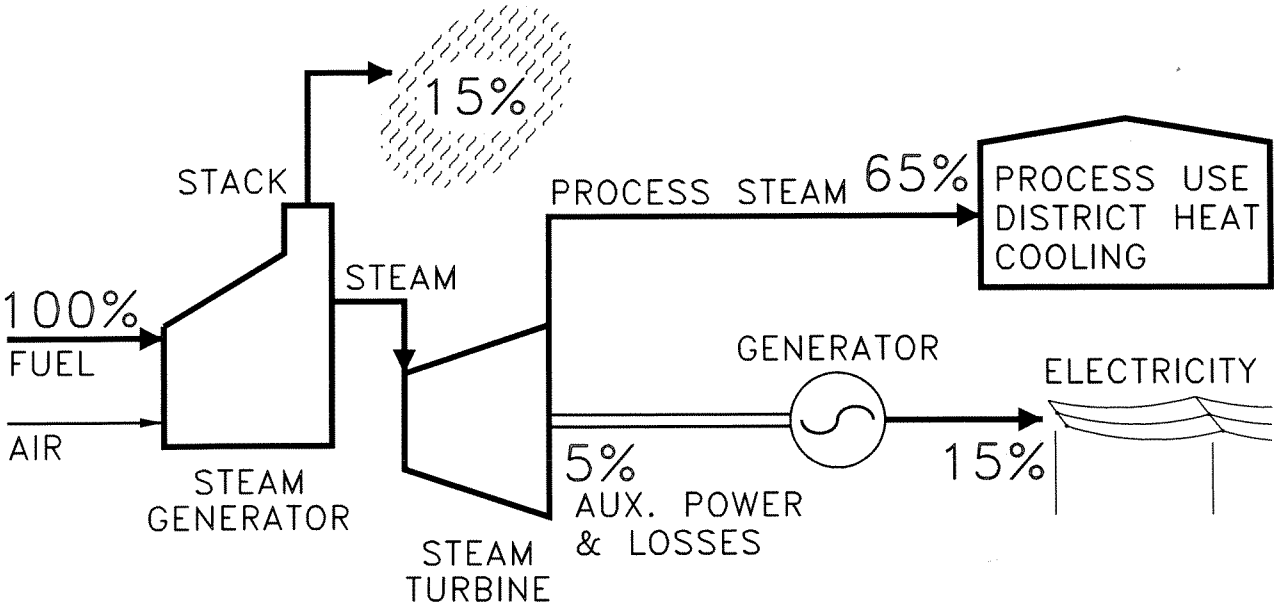




FUEL → ELECTRICITY → PROCESS HEAT

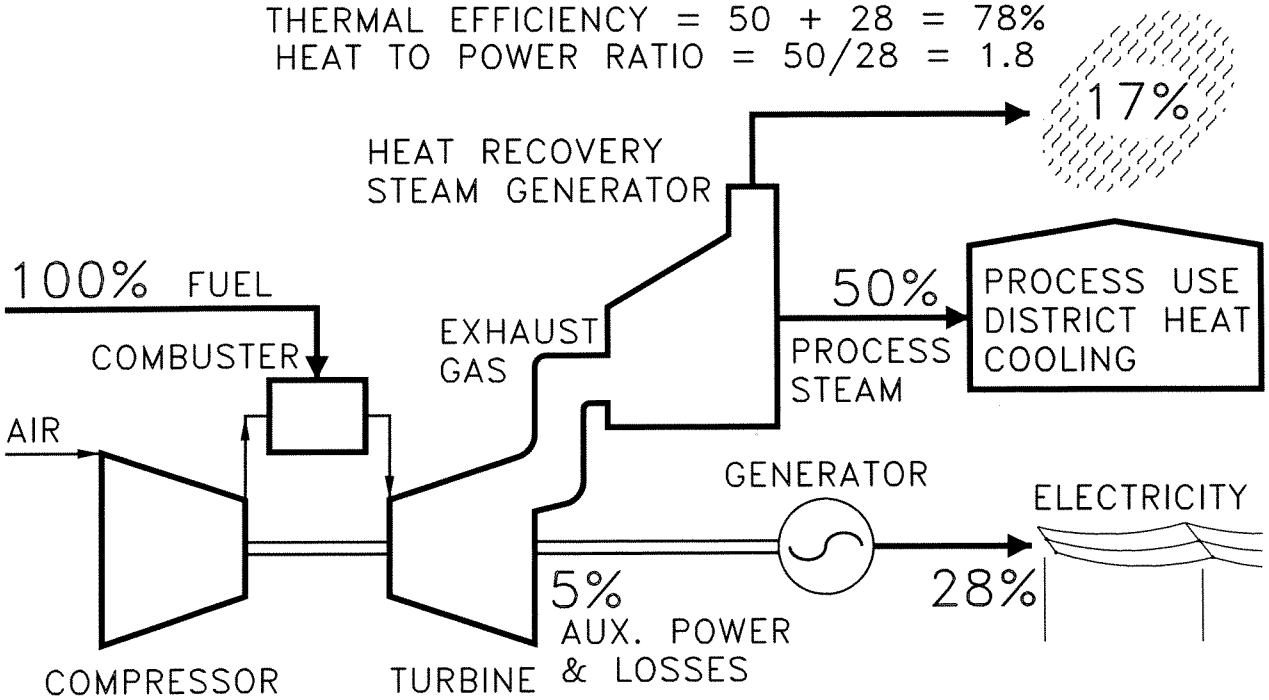
A. STEAM GENERATOR/STEAM TURBINE

THERMAL EFFICIENCY = 65 + 15 = 80%
HEAT TO POWER RATIO = 65/15 = 4.3



B. GAS TURBINE/HRSG

THERMAL EFFICIENCY = 50 + 28 = 78%
HEAT TO POWER RATIO = 50/28 = 1.8



ALL EFFICIENCIES ARE HHV

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INTERNATIONAL ENGINEERING SERVICES INC.

TOPPING CYCLES

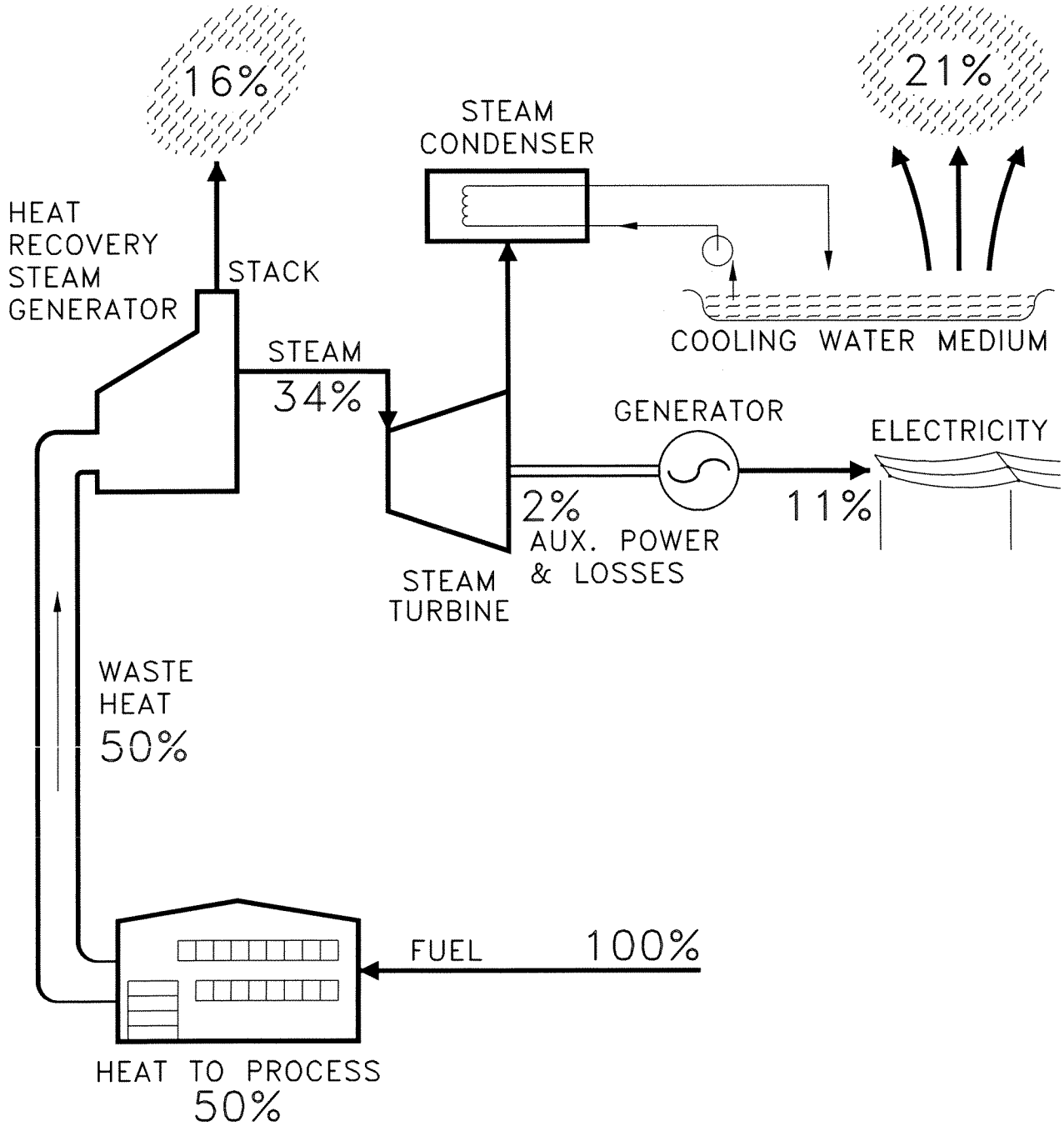
JAN. 2000

COGENERATION PRINCIPLES
EXHIBIT 1

FUEL → PROCESS HEAT → ELECTRICITY

HRSG/STEAM TURBINE

THERMAL EFFICIENCY = 50 + 11 = 61%
HEAT TO POWER RATIO = 50/11 = 4.5



ALL EFFICIENCIES ARE HHV

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BOTTOMING CYCLE

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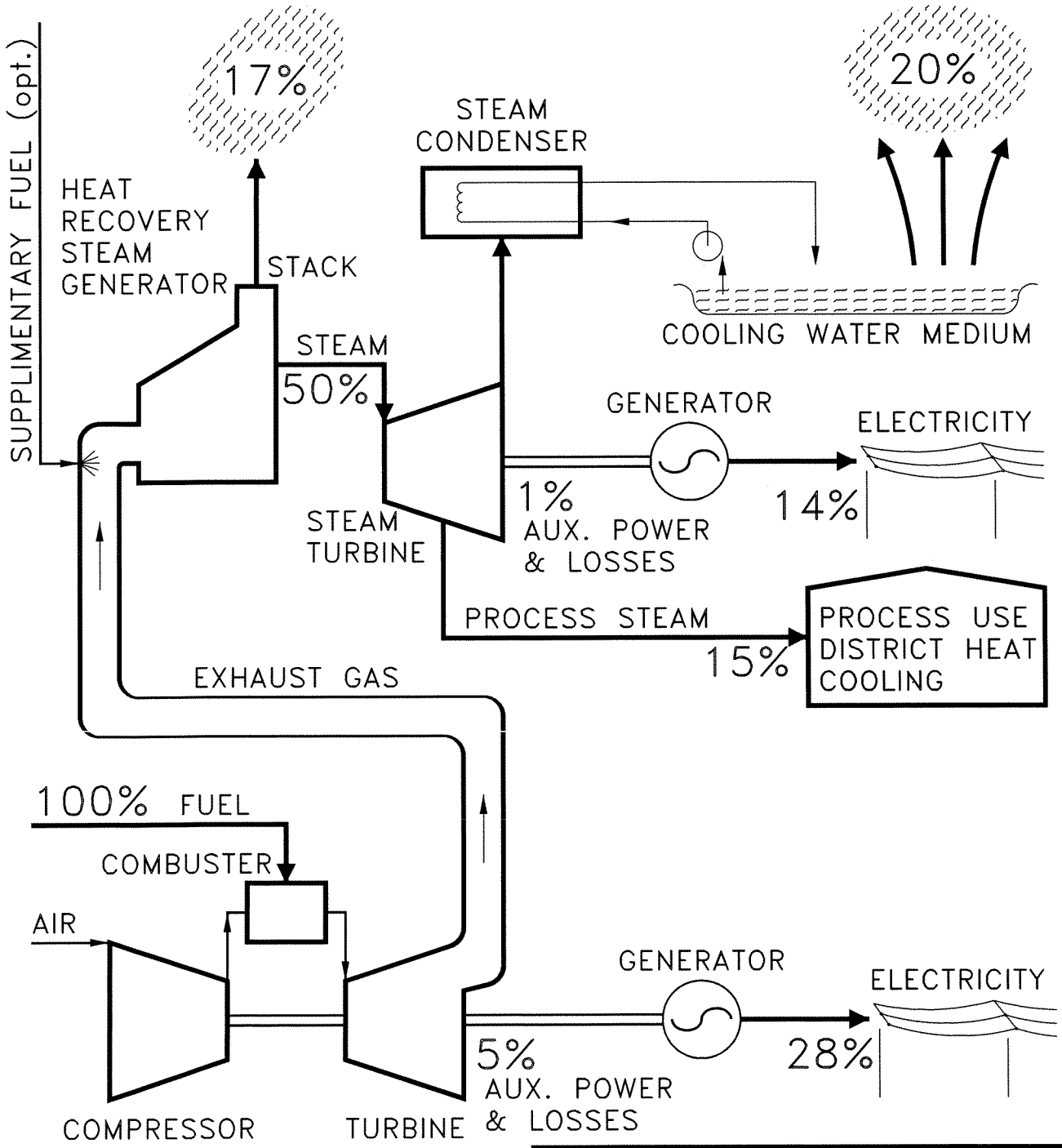
COGENERATION PRINCIPLES
EXHIBIT 2

FUEL → ELECTRICITY → PROCESS → ELECTRICITY

GAS TURBINE/HRSG/STEAM TURBINE

THERMAL EFFICIENCY = 28 + 15 +14 = 57%
HEAT TO POWER RATIO = 15/(28 + 14) = 0.36



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COMBINED CYCLE COGENERATION

ALL EFFICIENCIES ARE HHV

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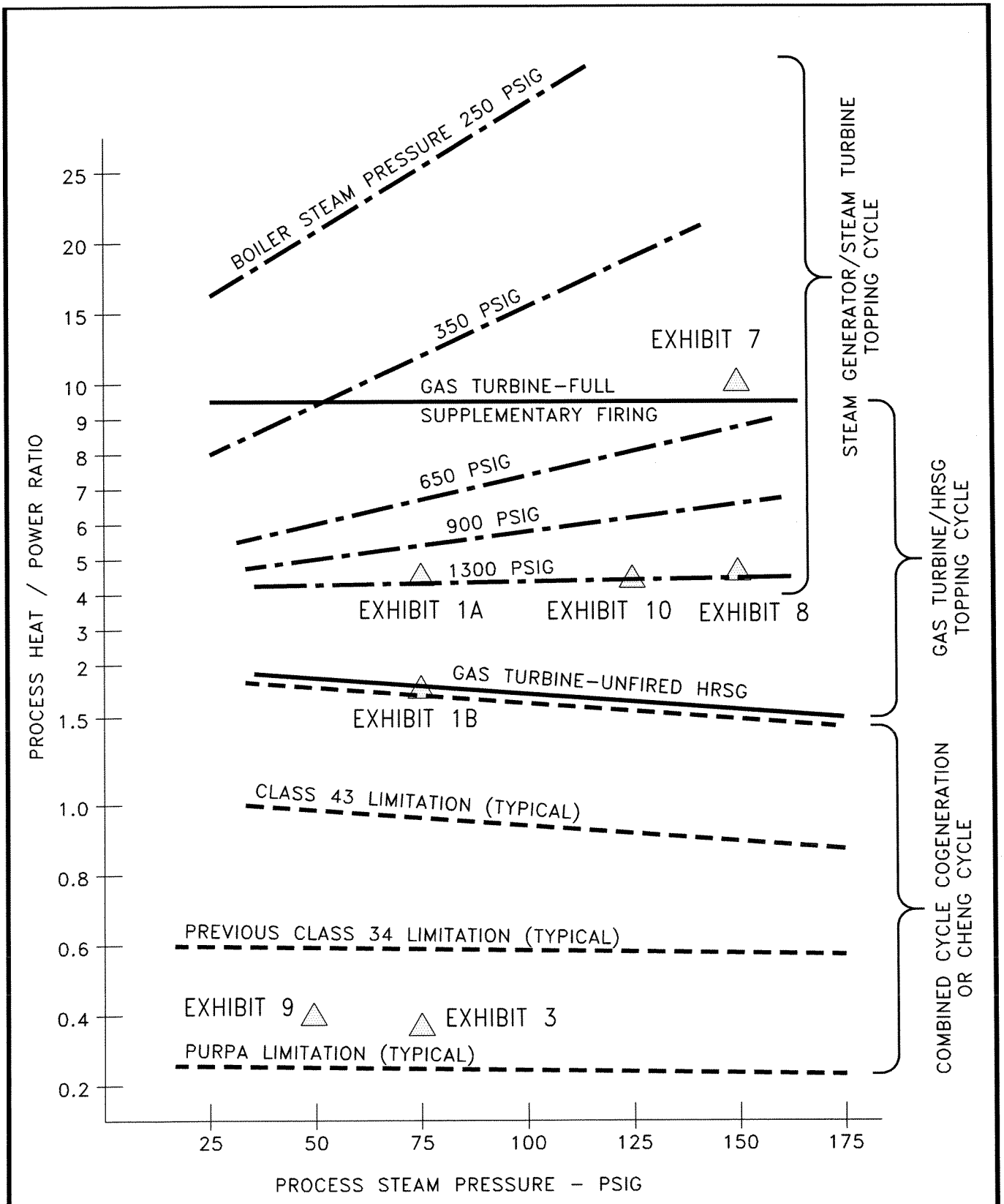
COGENERATION PRINCIPLES
EXHIBIT 3



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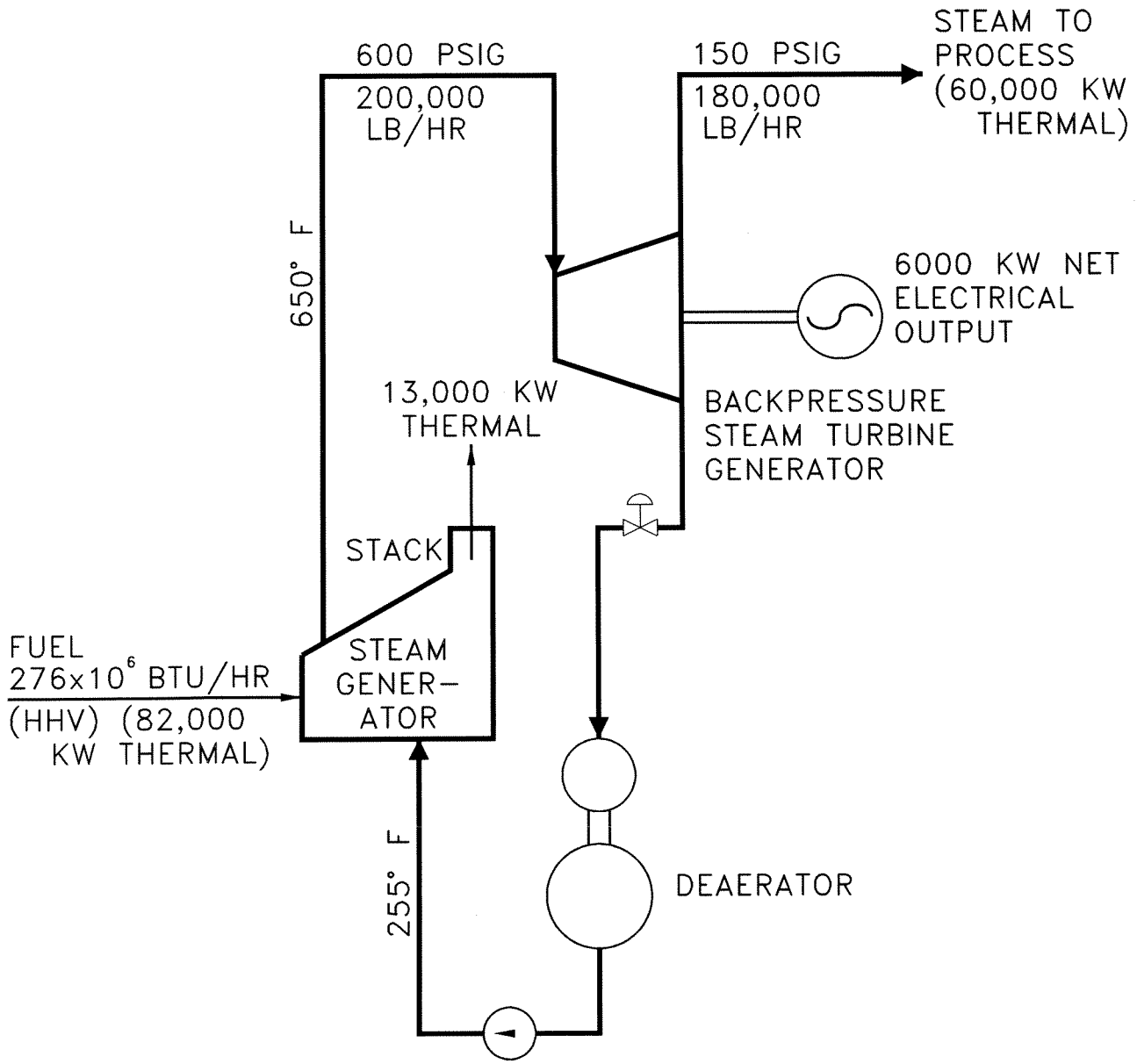
HEAT TO POWER RATIOS

JAN. 2000

COGENERATION PRINCIPLES
EXHIBIT 4

STEAM GENERATOR/BACKPRESSURE STEAM TURBINE



LOSSES AND AUXILIARY POWER = 3000 KW

HHV THERMAL EFFICIENCY $= \frac{6000+60,000}{82,000} = 80\%$

HEAT/POWER RATIO $= \frac{60,000}{6000} = 10$

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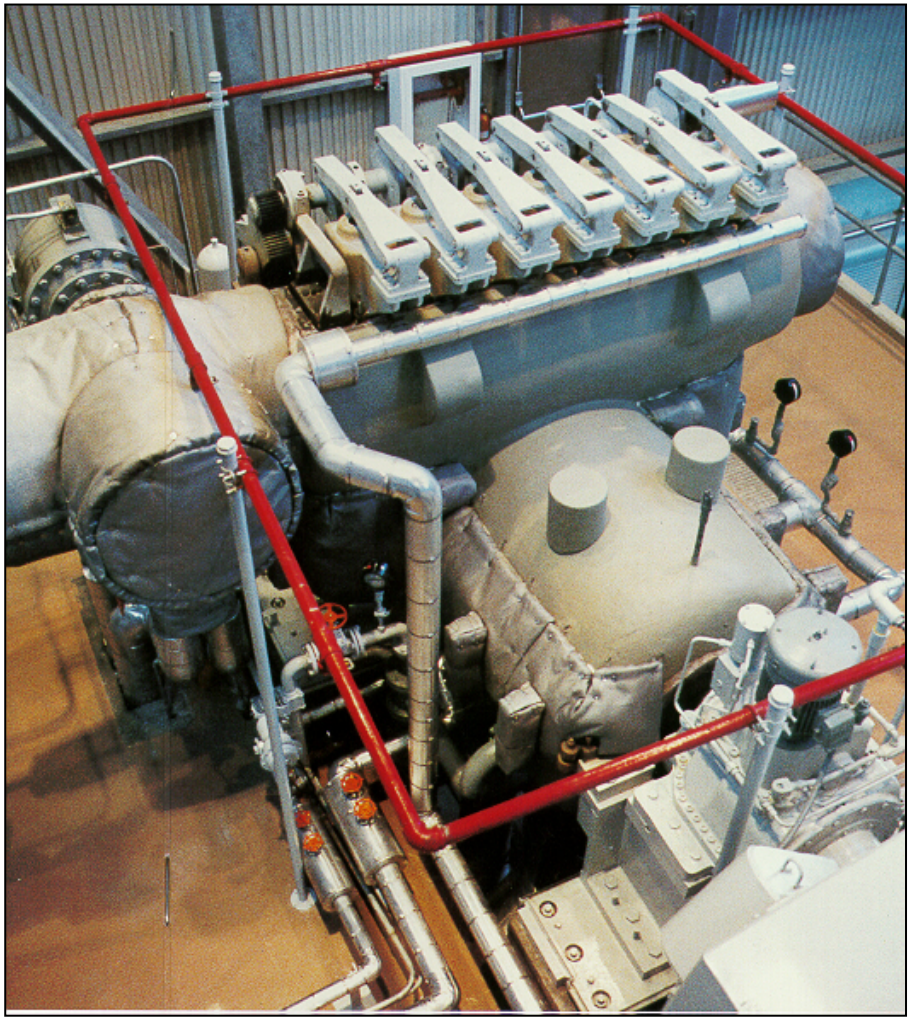
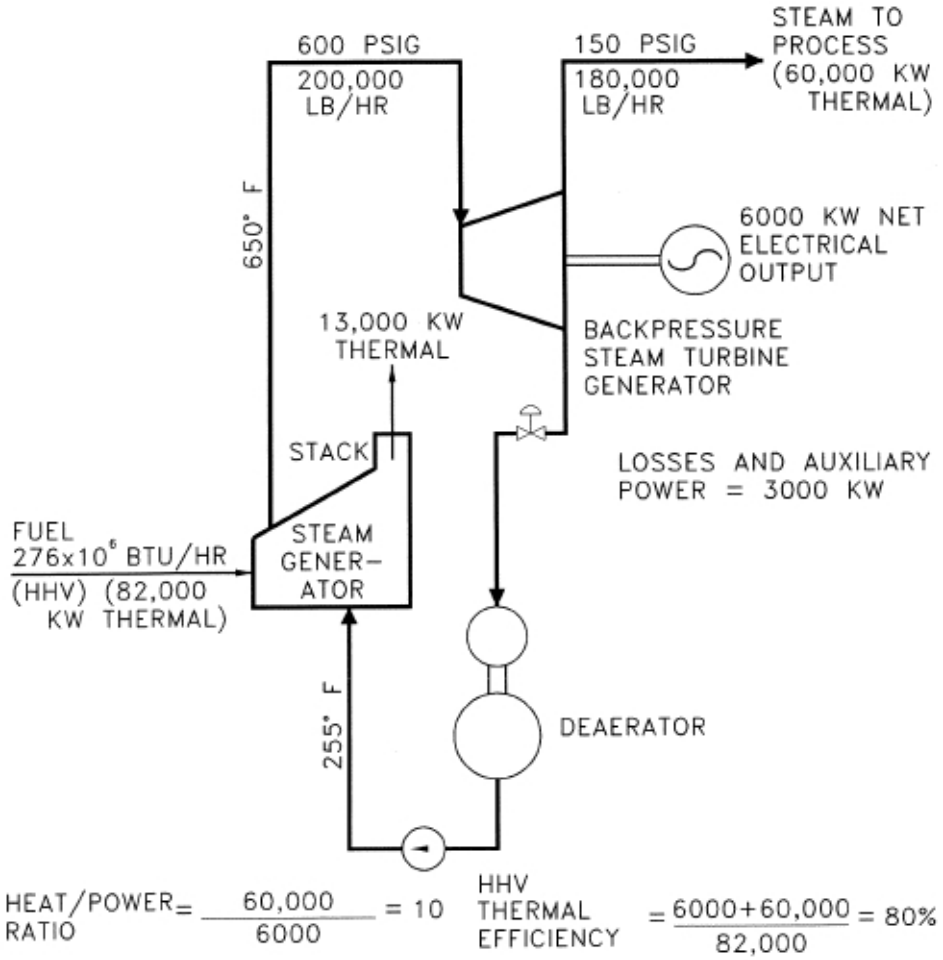
TYPICAL HEAT BALANCE
ALUMINA PLANT APPLICATION

JAN. 2000

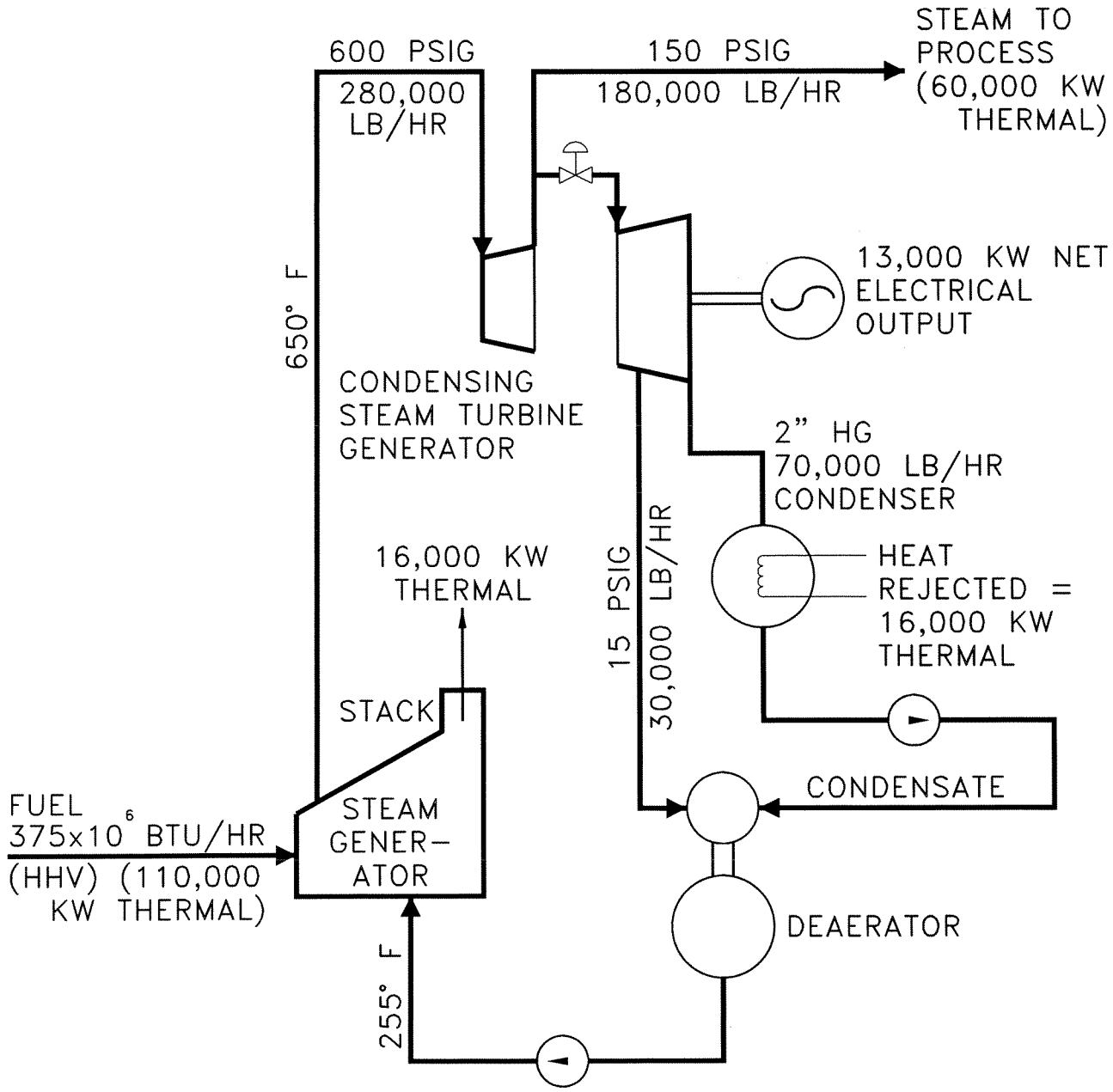
COGENERATION PRINCIPLES
EXHIBIT 5

Exhibit #5 – Steam-Generator and Back-Pressure Steam Turbine





STEAM GENERATOR/CONDENSING STEAM TURBINE



LOSSES AND AUXILIARY POWER = 5000 KW

$$\text{HHV THERMAL EFFICIENCY} = \frac{13{,}000+60{,}000}{110{,}000} = 66.4\%$$

$$\text{HEAT/POWER RATIO} = \frac{60{,}000}{13{,}000} = 4.6$$

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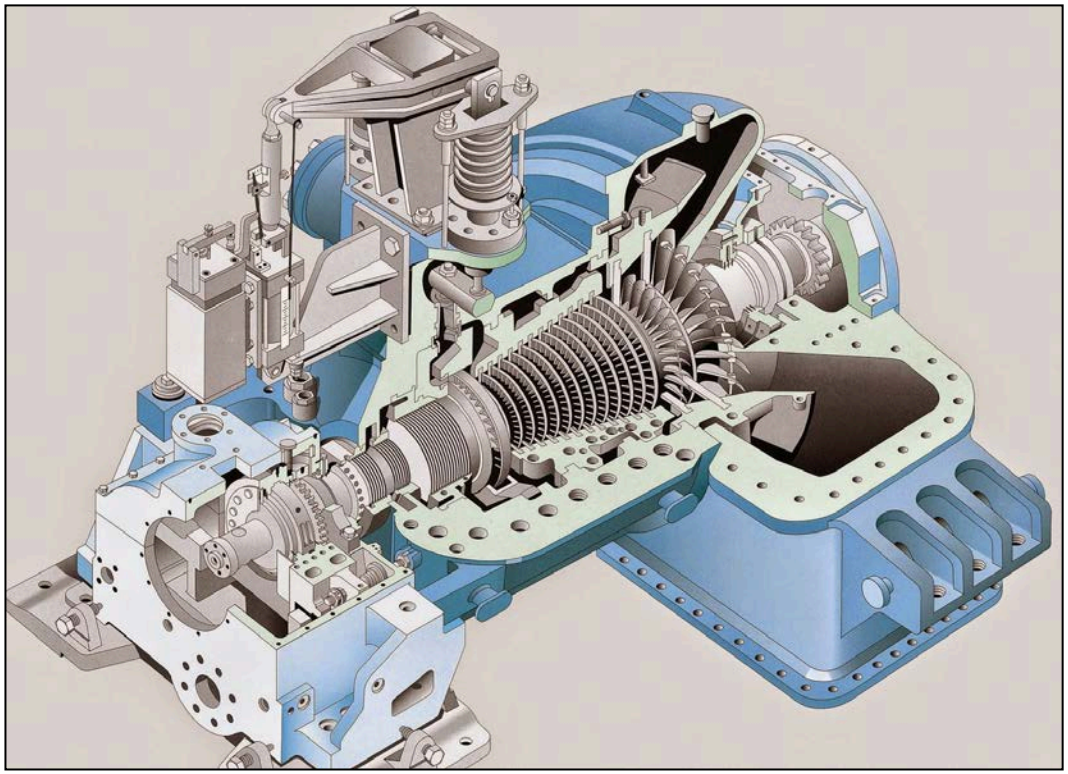
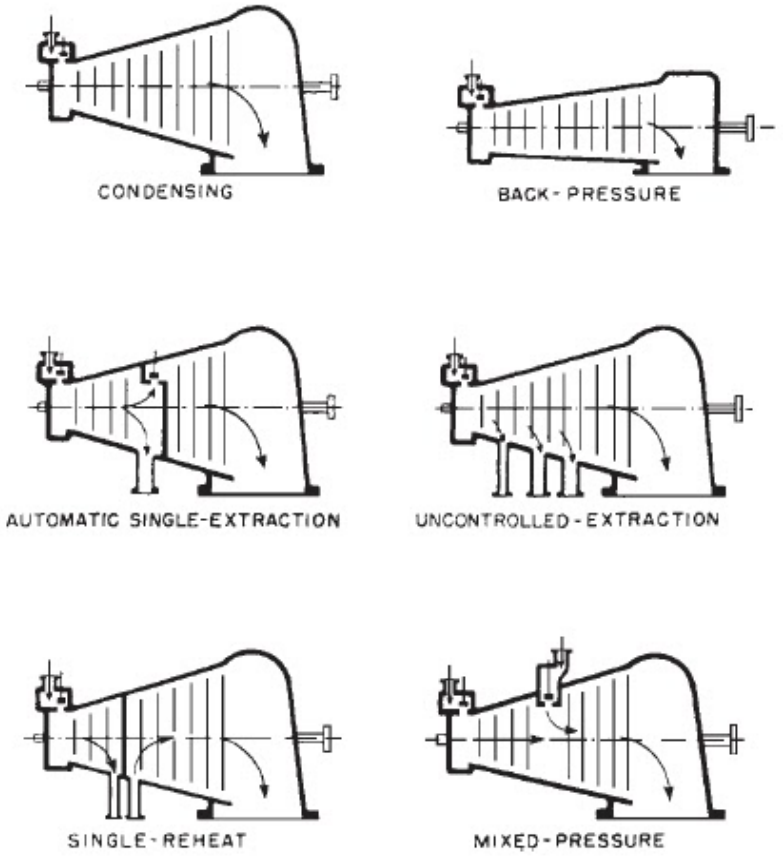
TYPICAL HEAT BALANCE PULP & PAPER APPLICATION

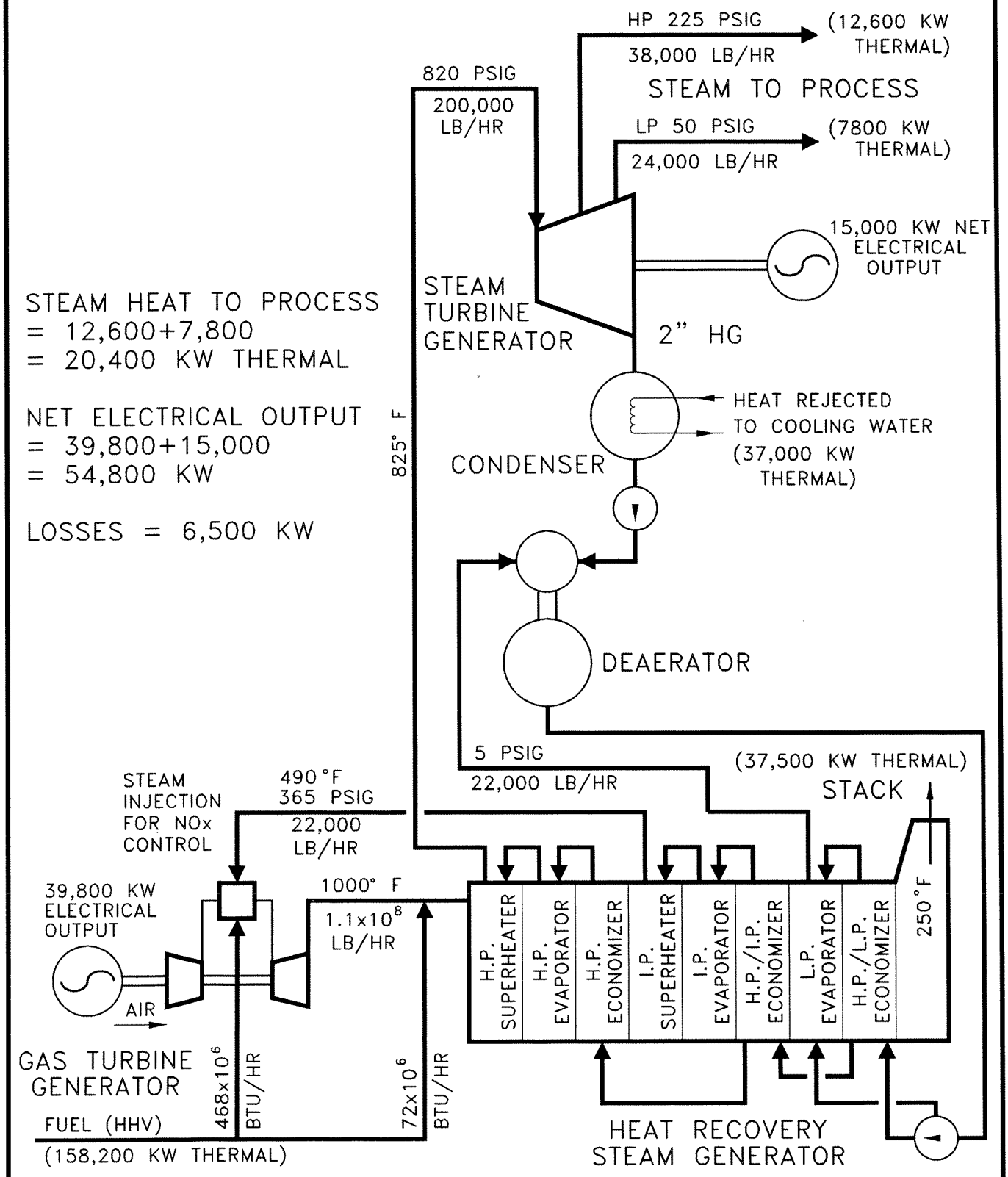
JAN. 2000	COGENERATION PRINCIPLES EXHIBIT 6

Exhibit #6 – Steam-Generator and Condensing Steam Turbine





COMBINED CYCLE COGENERATION



STEAM HEAT TO PROCESS
= 12,600+7,800
= 20,400 KW THERMAL

NET ELECTRICAL OUTPUT
= 39,800+15,000
= 54,800 KW

LOSSES = 6,500 KW

$$\text{HHV THERMAL EFFICIENCY} = \frac{54{,}800+20{,}400}{158{,}200} = 47.5\%$$

$$\text{HEAT/POWER RATIO} = \frac{20{,}400}{54{,}800} = 0.4$$

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TYPICAL HEAT BALANCE COMBINED CYCLE APPLICATION

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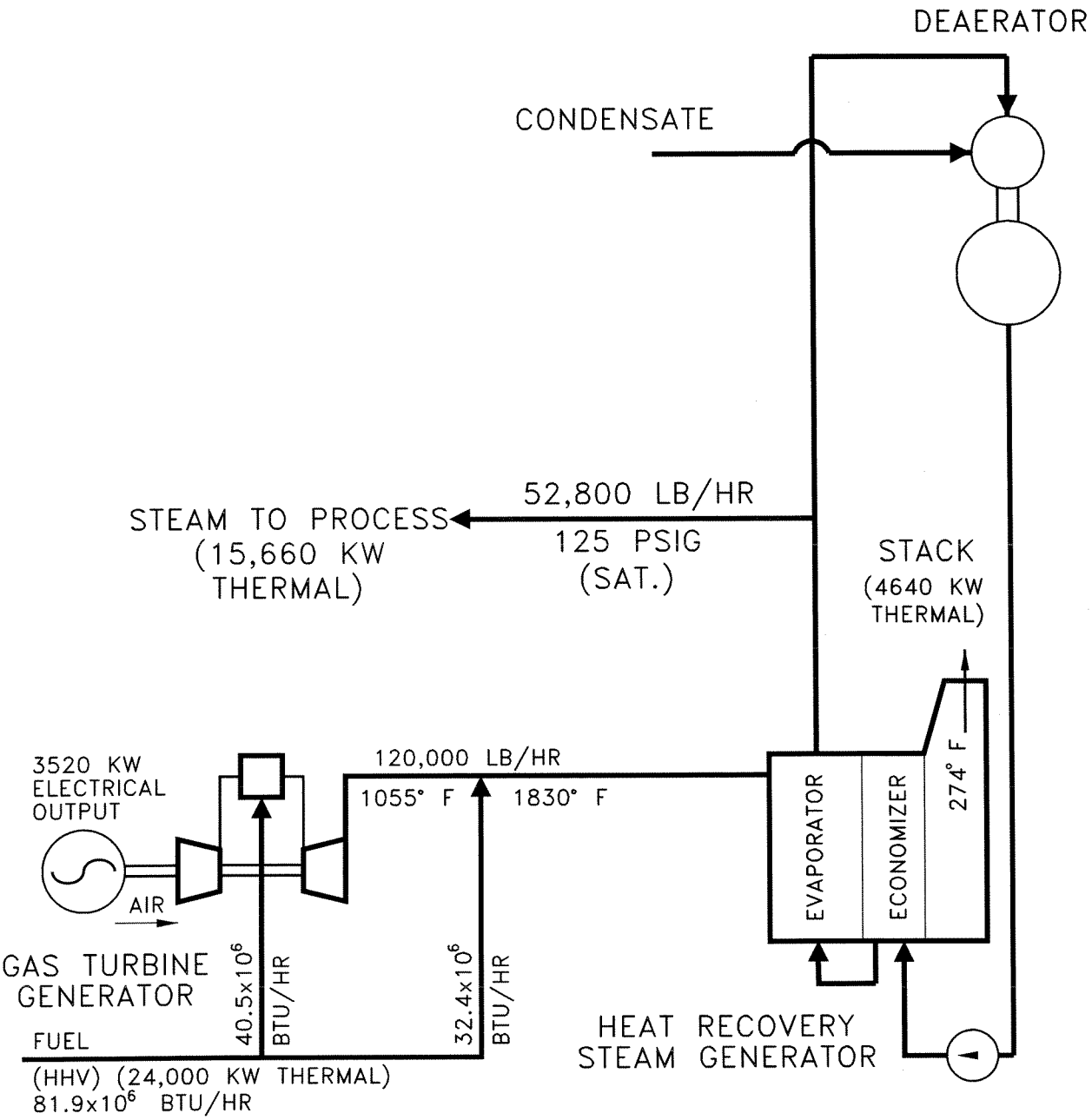
COGENERATION PRINCIPLES
EXHIBIT 7

Exhibit #7 – Combined-Cycle Cogeneration
(Lake Superior Power)

GAS TURBINE GENERATOR/HEAT RECOVERY STEAM GENERATOR



LOSSES AND AUXILIARY
POWER = 600 KW

$$\text{HHV THERMAL EFFICIENCY} = \frac{3520+15,660}{24,000} = 80\%$$

$$\text{HEAT/POWER RATIO} = \frac{15,660}{3520} = 4.4$$

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TYPICAL HEAT BALANCE
SMALL PROCESS PLANT APPLICATION

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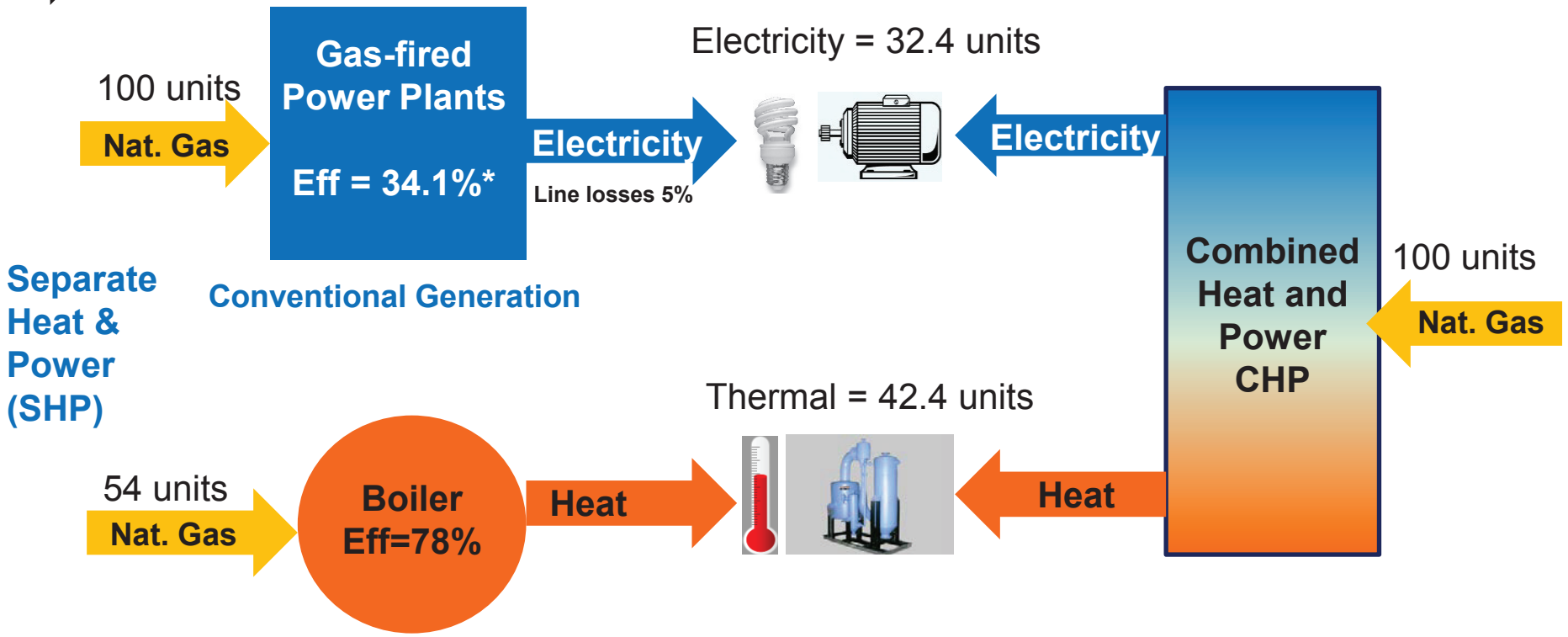
COGENERATION PRINCIPLES
EXHIBIT 8

Exhibit #8 – Gas Turbine & HRSG
(Whitby Cogeneration)

World's 1st Rolls-Royce Trent DLE
IST dual-pressure OTSG (once-through steam generator)

How CHP Saves Gas

CHP vs. Separate Heat and Power (SHP)



Total gas consumption = 154 units
Overall efficiency = 48%

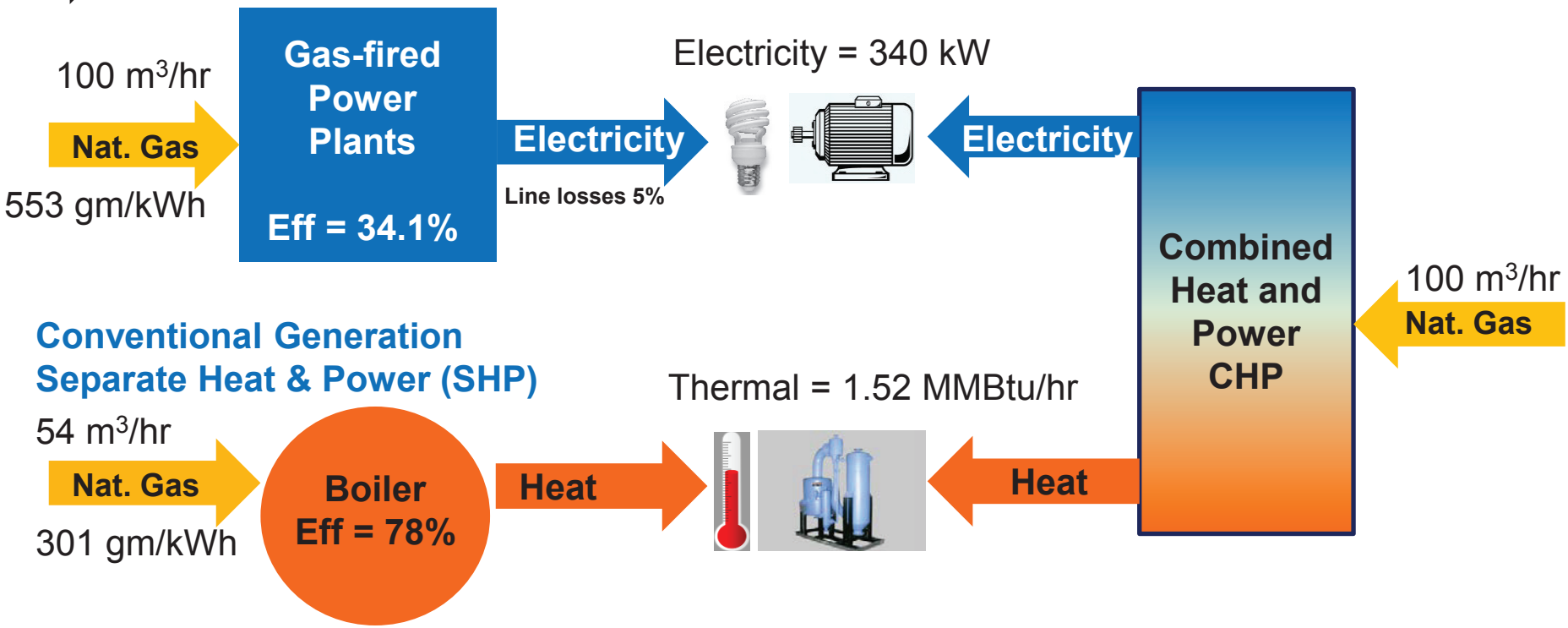
Total gas consumption = 100 units
Overall efficiency = 75%

Gas Saving = 54 units or 35% of gas used in conventional generation
(Annual savings depend on operating hours of power plants and CHP)

Note: * Based on Intrinsik report for OPG (2016), All values reported on higher heating value

How CHP Reduces GHG Emissions

CHP vs. Separate Heat and Power (SHP)



Total gas consumption = 154 m^3/hr
CO2e emissions = 0.29 tonne/hr
= 854 gm/kWh

Total gas consumption = 100 m^3/hr
CO2e emissions = 0.188 tonne/hr
= 553 gm/kWh

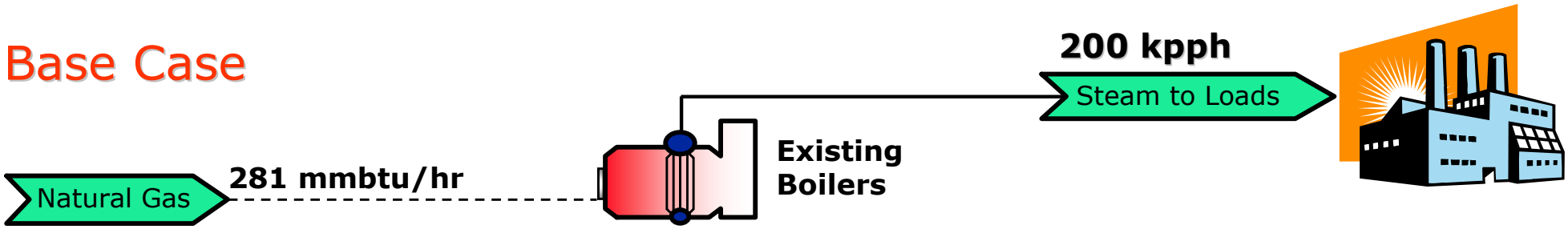
CO2e Reduction = 301 gm/kWh of displaced electricity from gas plants
(Annual savings depend on operating hours of power plants and CHP)

ENBRIDGE

Note: * Based on Intrinsik report for OPG (2016), All values reported on higher heating value

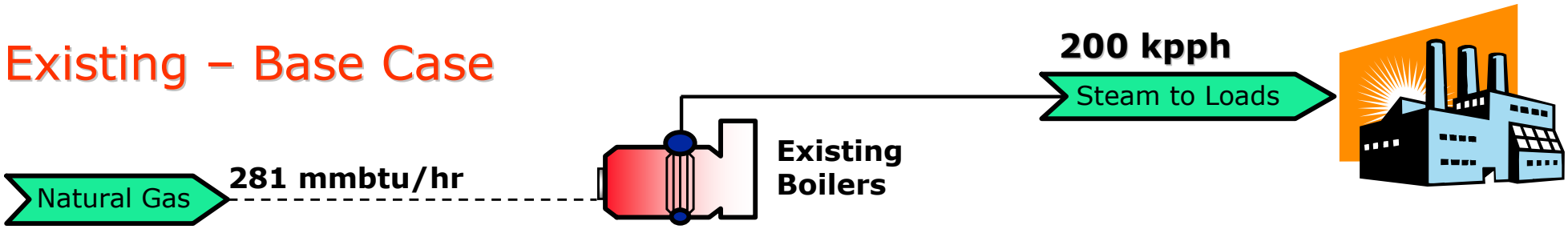
COGENERATION EXAMPLE

Base Case



COGENERATION EXAMPLE

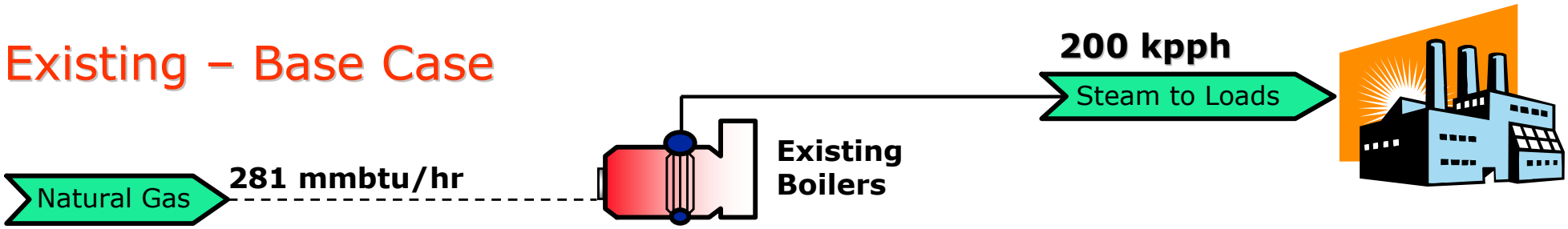
Existing – Base Case



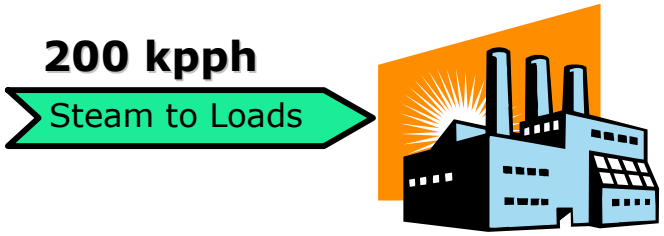
Cogeneration Case

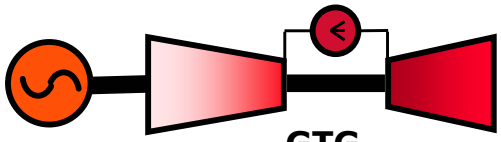
COGENERATION EXAMPLE

Existing – Base Case



Cogeneration Case

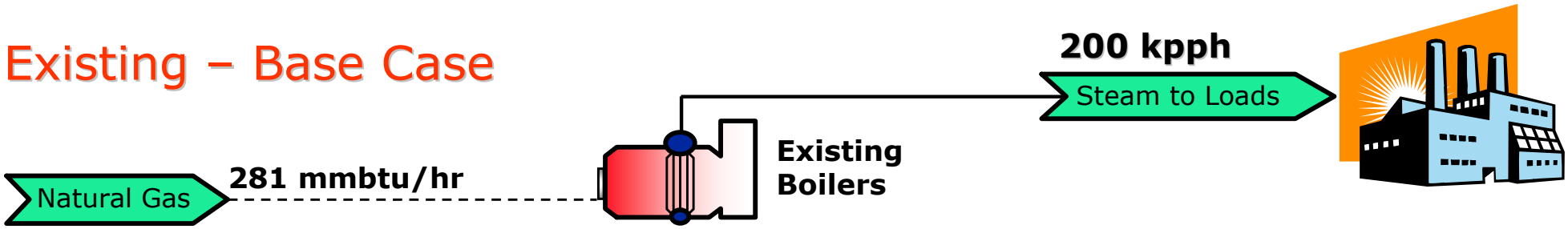




GTG
Gas Turbine Generator

COGENERATION EXAMPLE

Existing – Base Case



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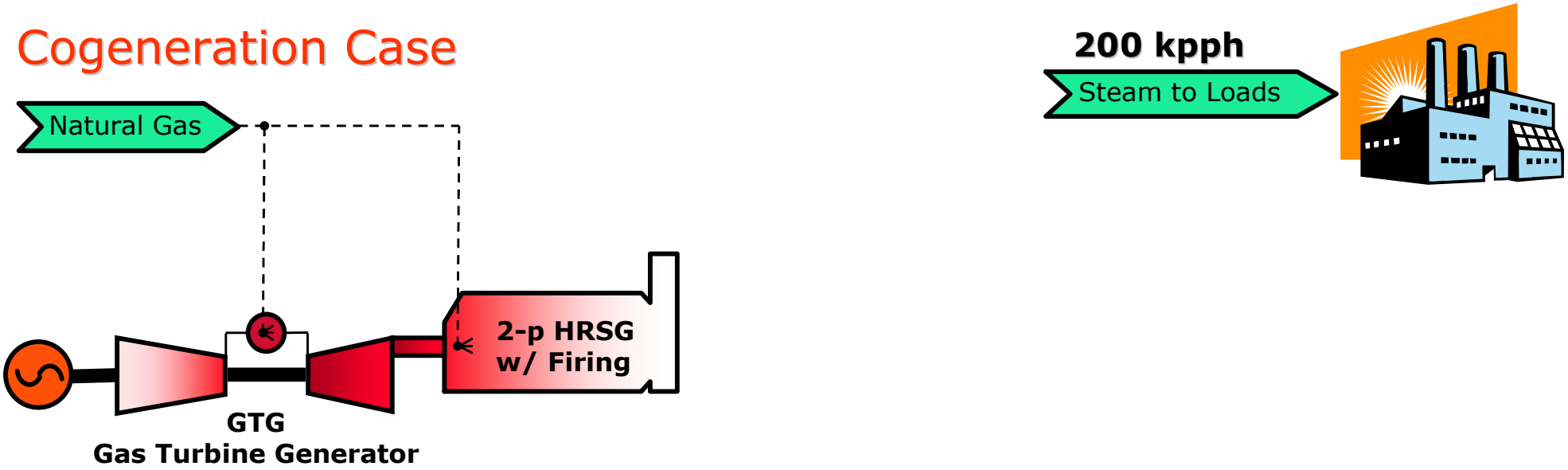
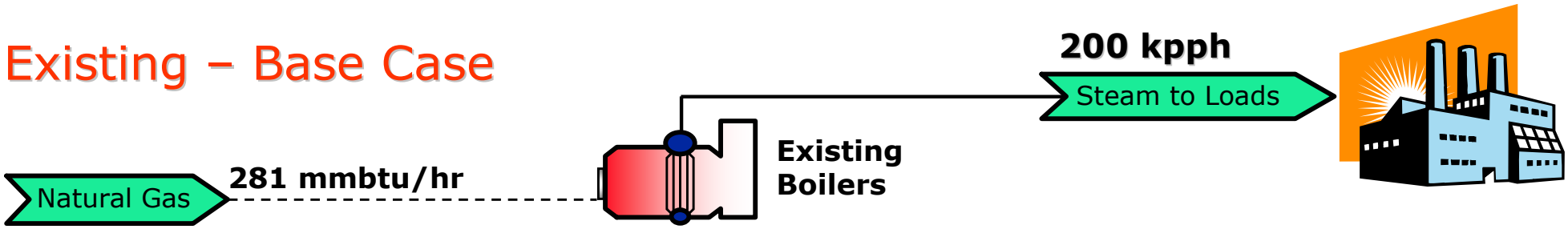


COGENERATION EXAMPLE

Existing – Base Case



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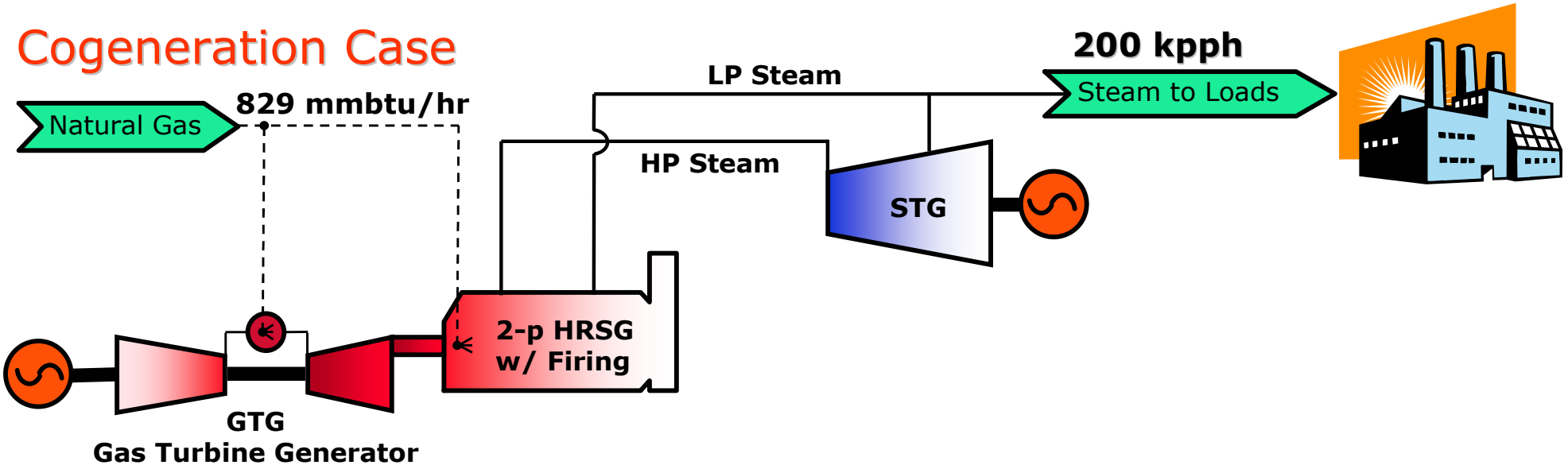

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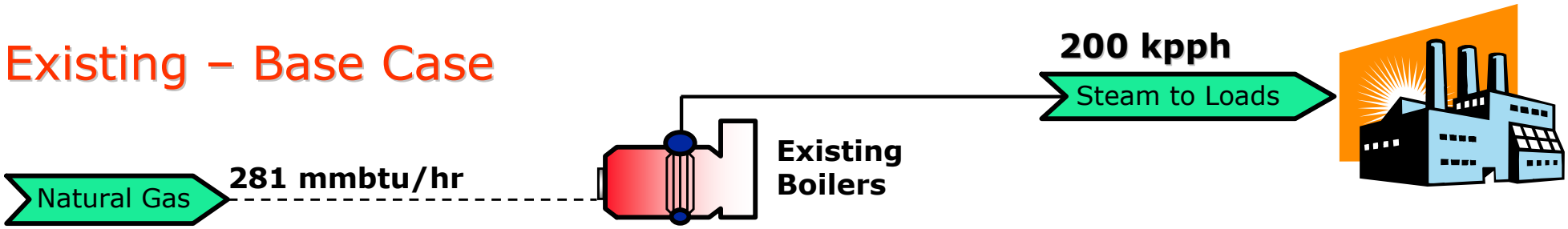
Existing – Base Case



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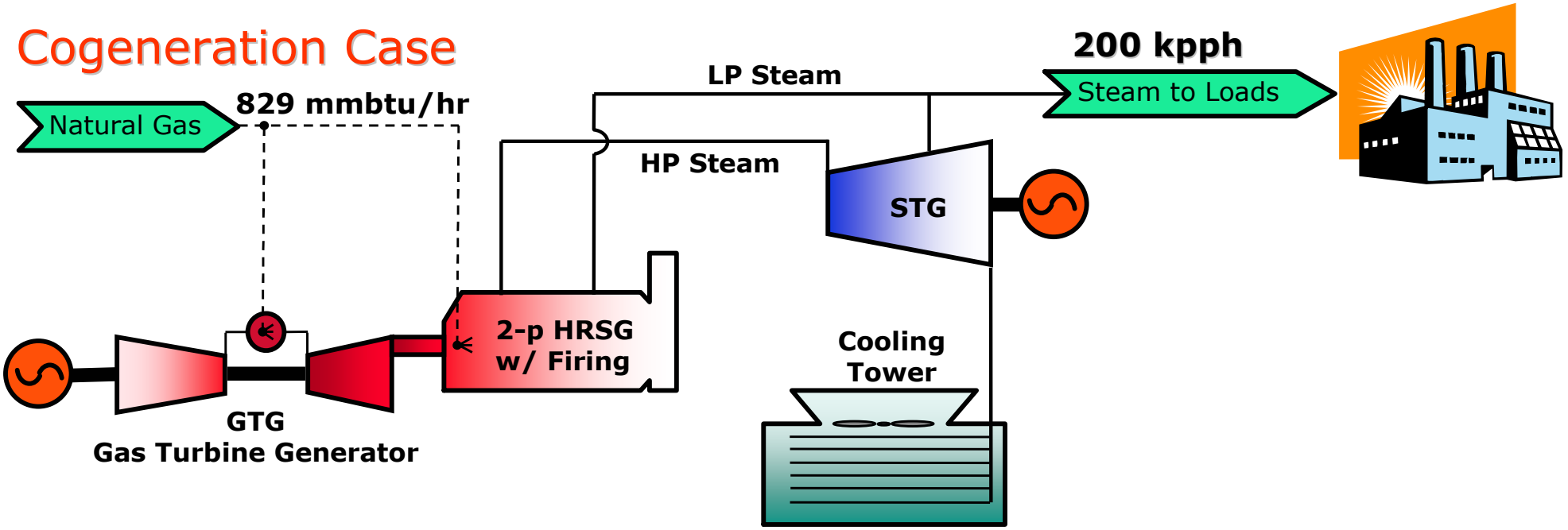

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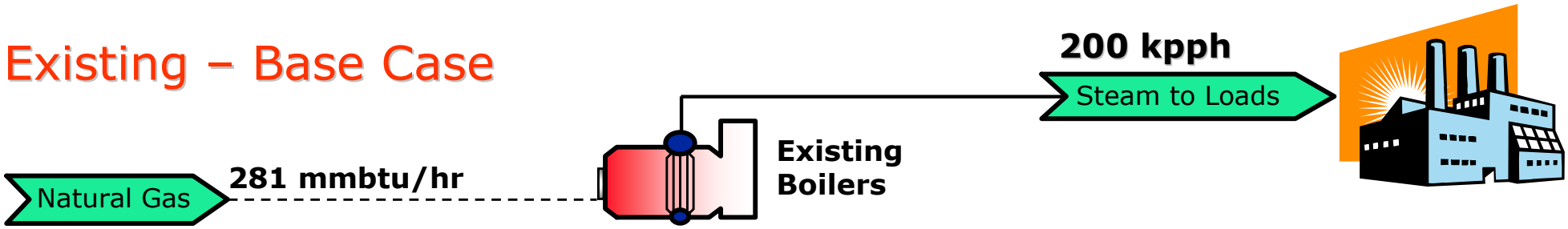
Existing – Base Case



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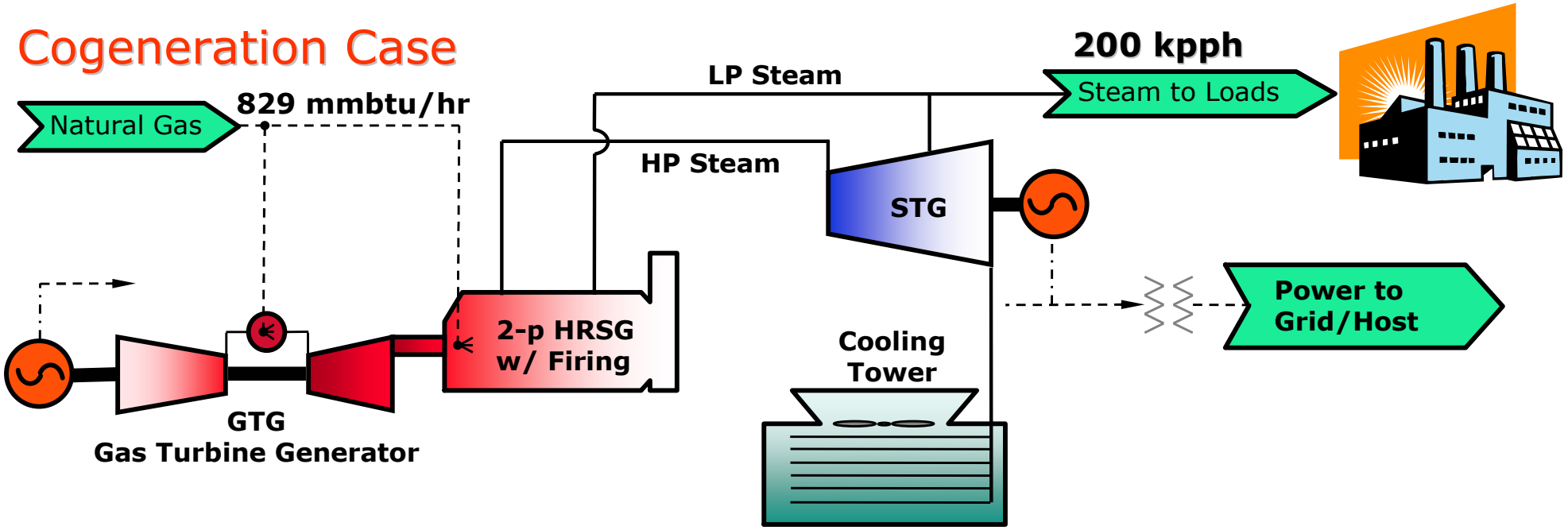

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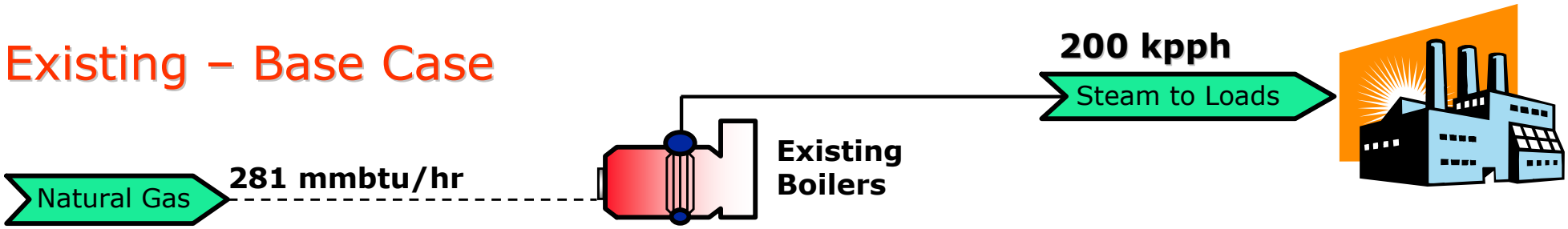
Existing – Base Case



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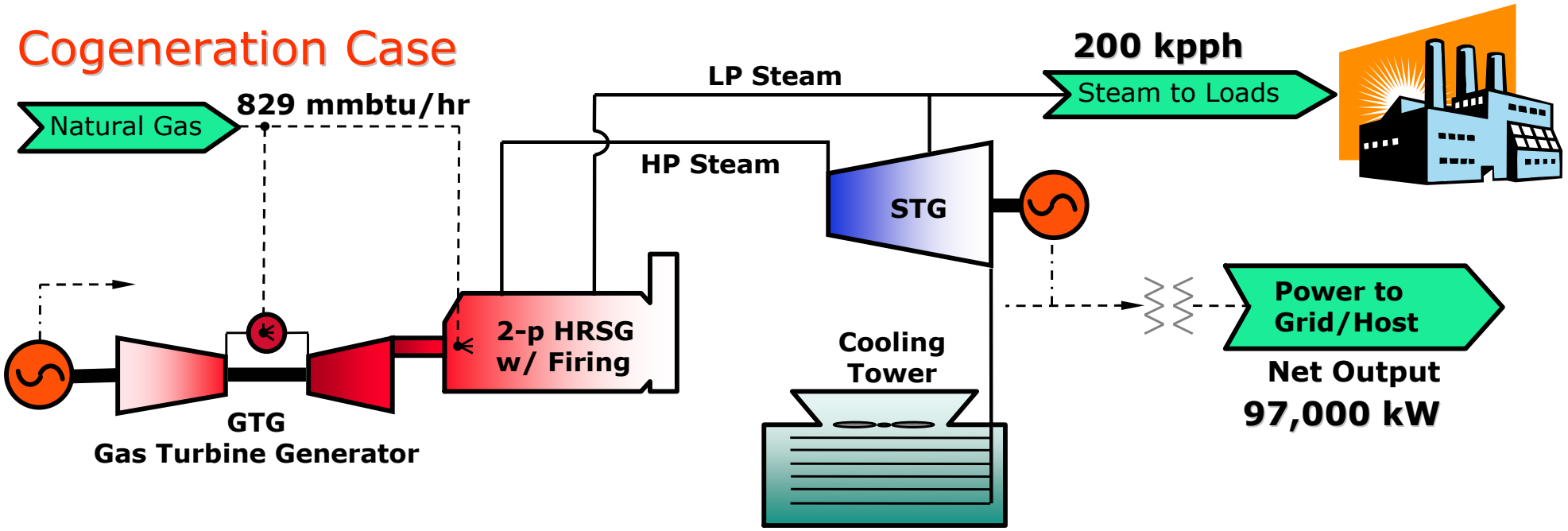
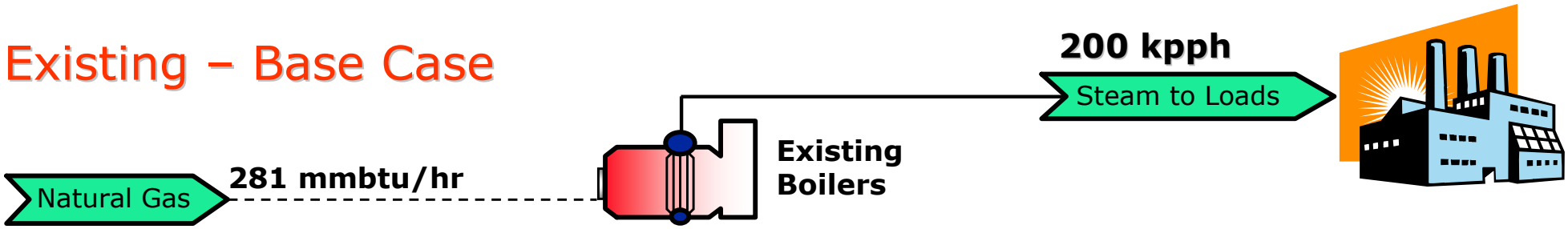
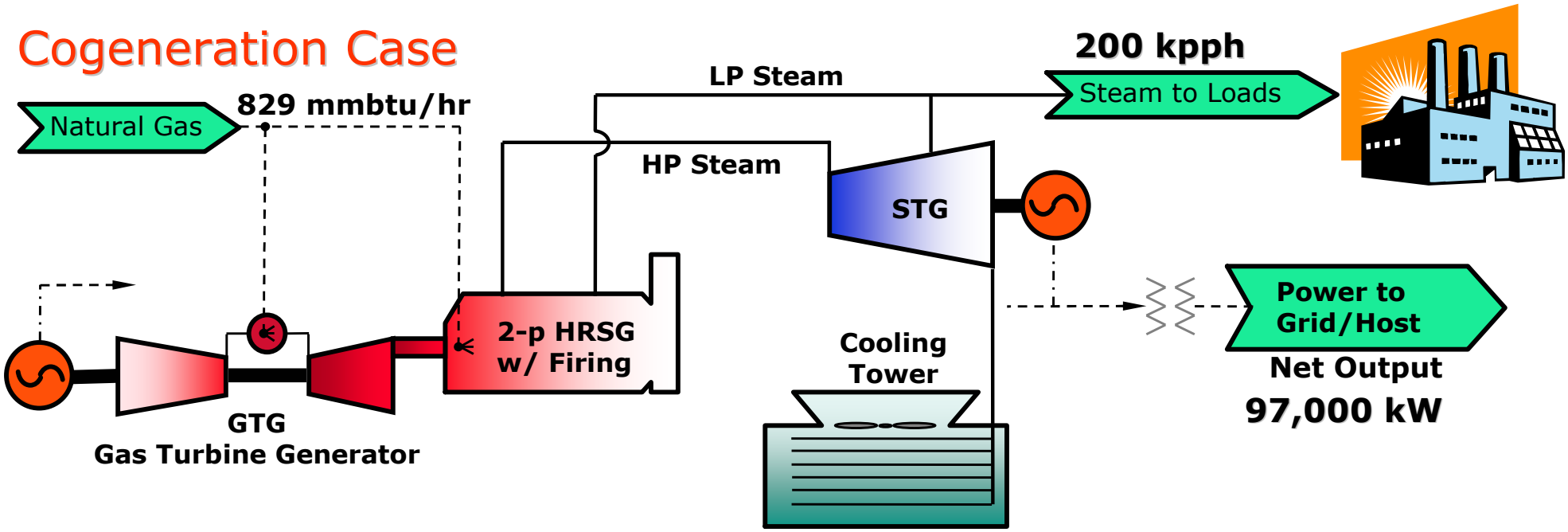


COGENERATION EXAMPLE

Existing – Base Case



Cogeneration Case

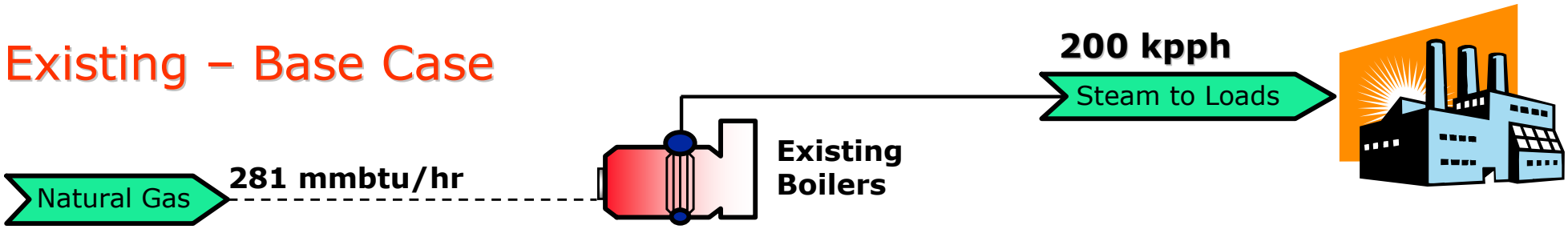


Cycle Inputs:
Fuel: 829 mmbtu/hr

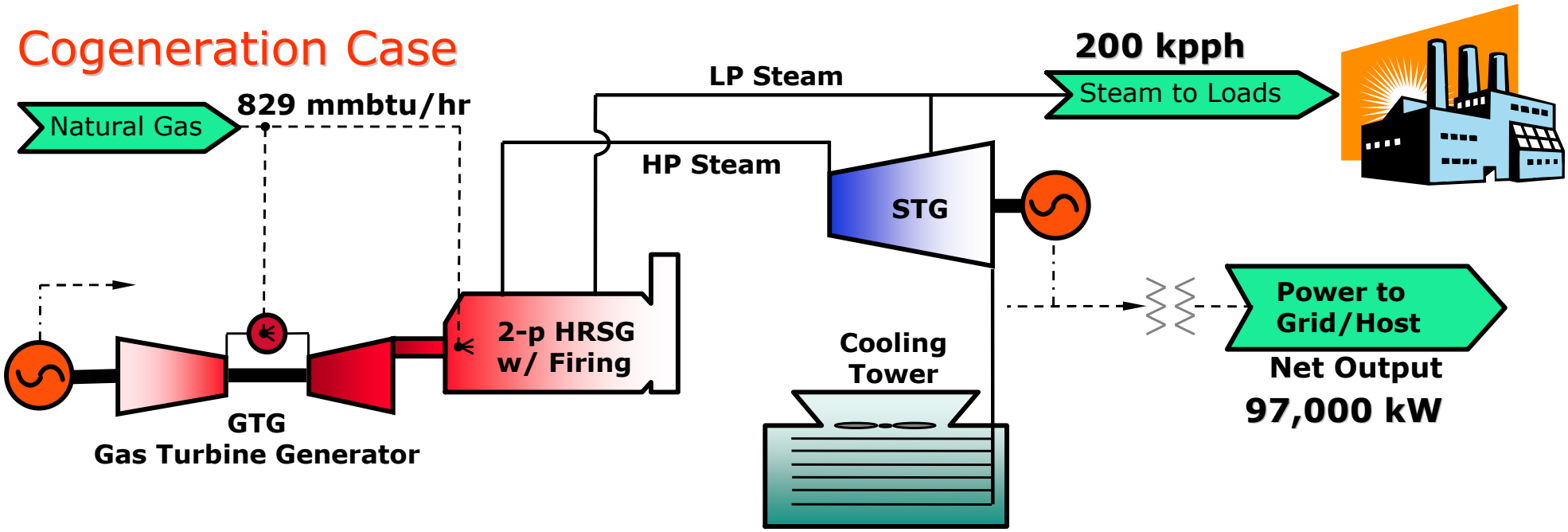
Cycle Outputs:
Steam: 200 kpph
Power: 97,000 kW

COGENERATION EXAMPLE

Existing – Base Case



Cogeneration Case



Cycle Inputs:
Fuel: 829 mmbtu/hr

Cycle Outputs:
Steam: 200 kpph
Power: 97,000 kW

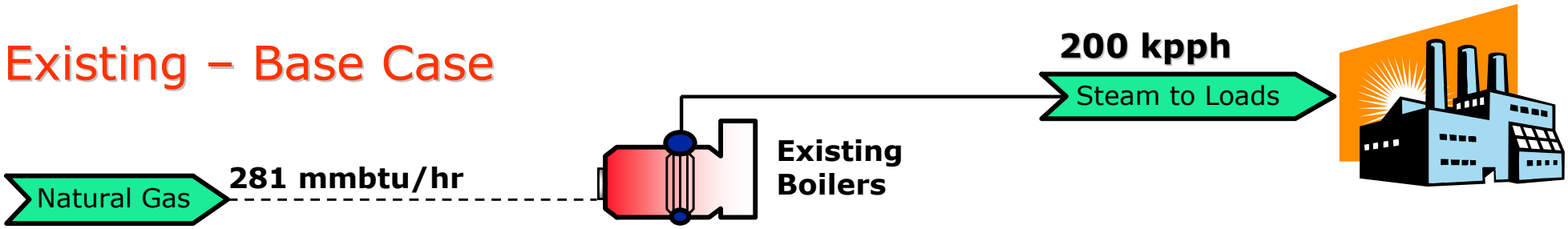
Cogeneration or CHP Efficiency

$$\frac{[200{,}000 \times 1000] + [97{,}000 \times 3413]}{829{,}000{,}000}$$

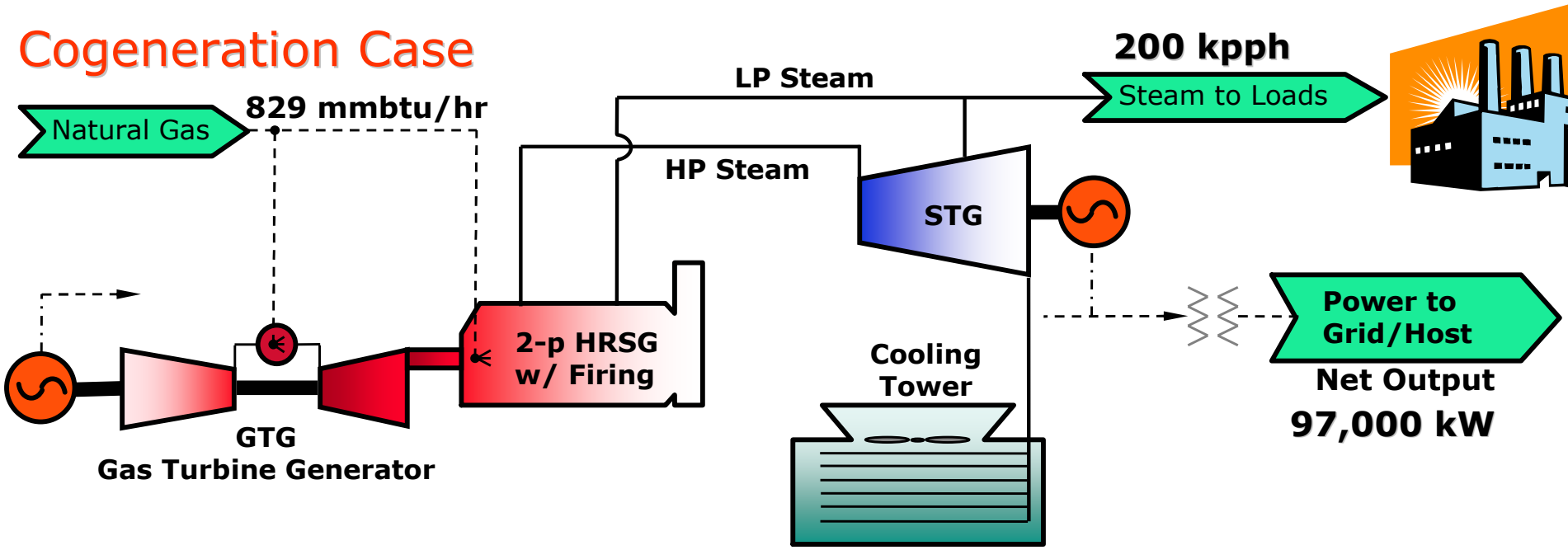
= 64% (or a Heat Rate of **5328** btu/kW.hr)

COGENERATION EXAMPLE

Existing – Base Case



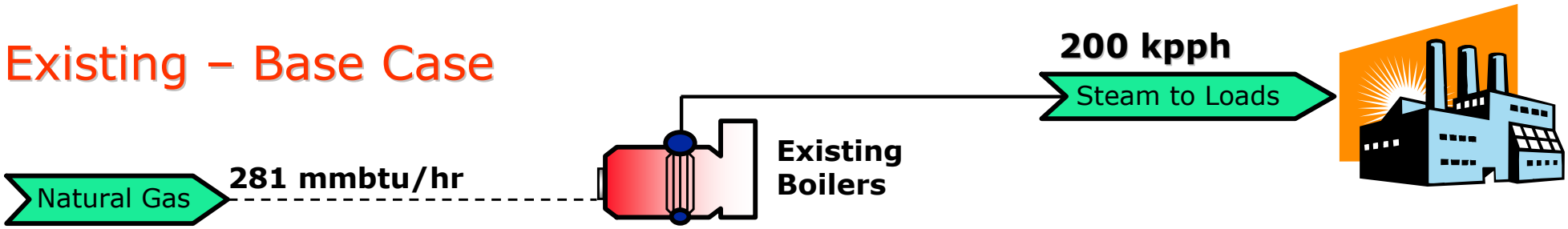
Cogeneration Case



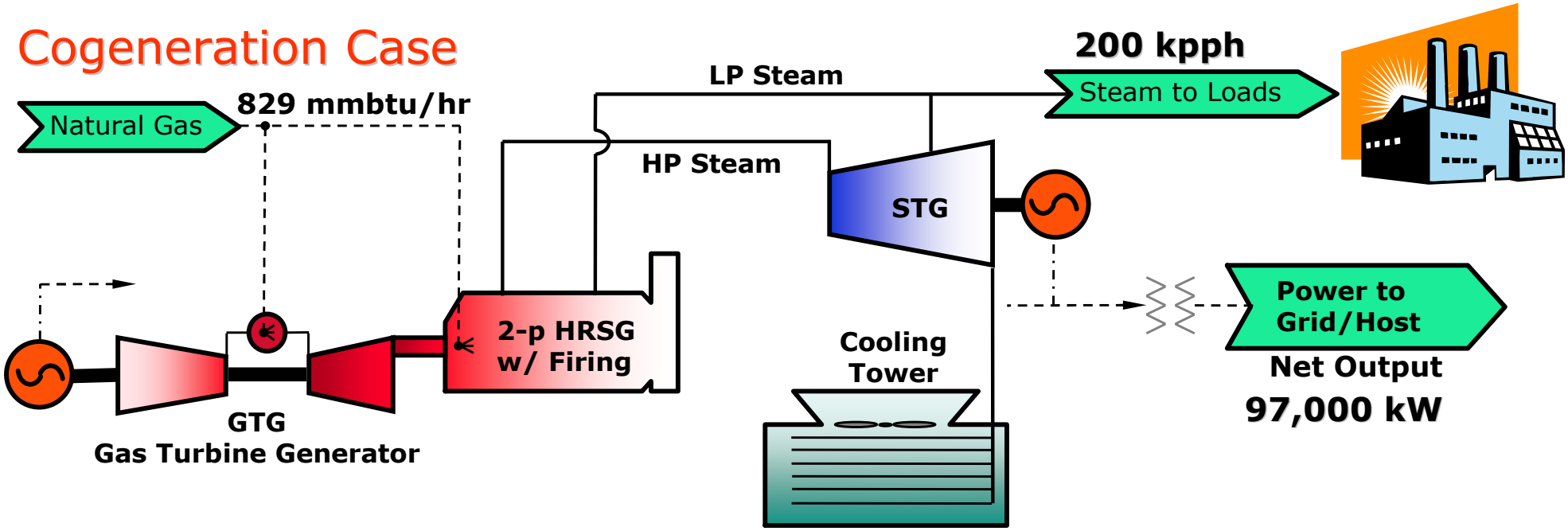
Total Cogeneration Fuel 829 mmbtu/hr

COGENERATION EXAMPLE

Existing – Base Case



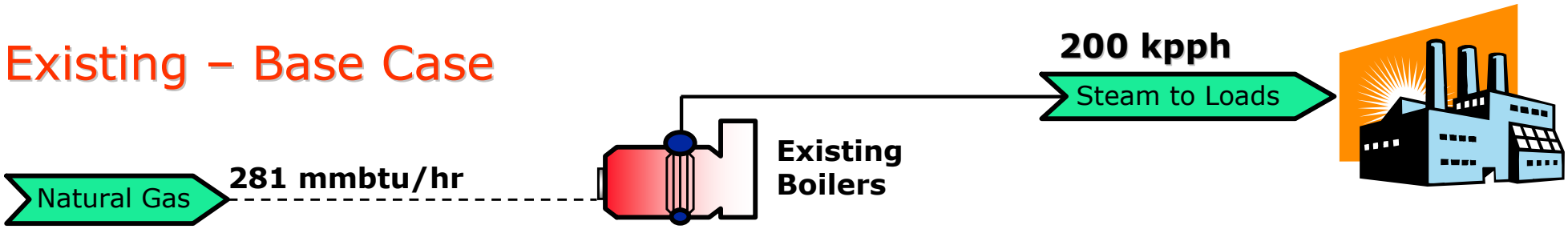
Cogeneration Case



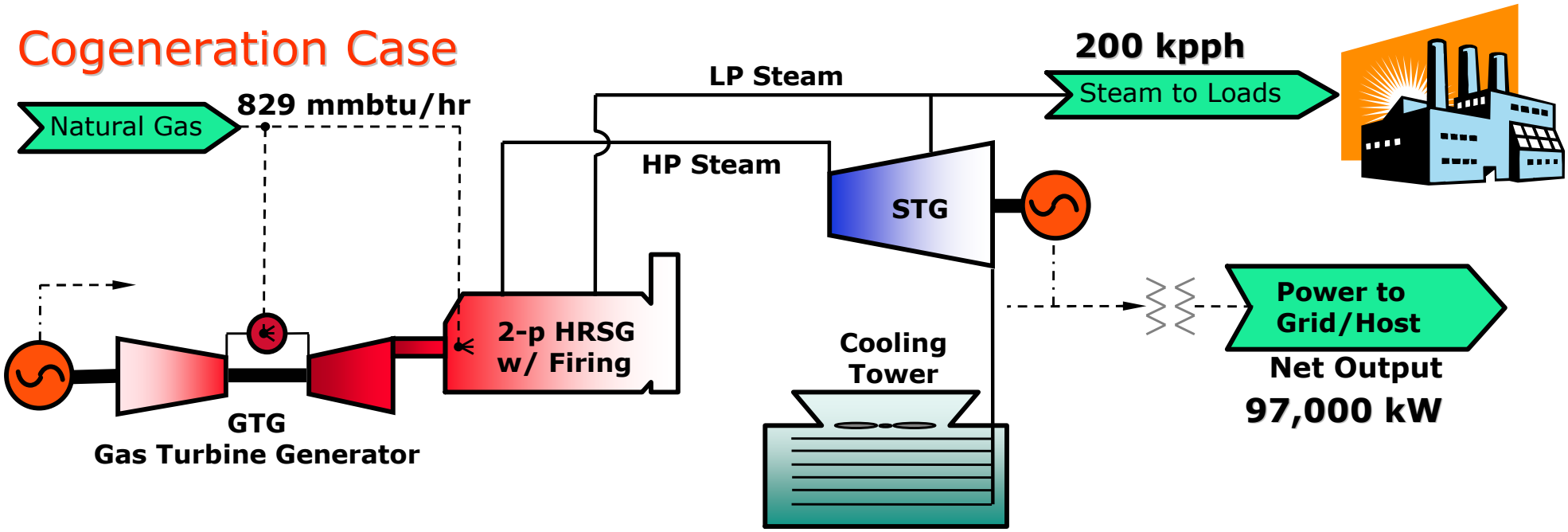
Total Cogeneration Fuel	829 mmbtu/hr
Fuel-Chargeable-to-Steam (FCS)	281 mmbtu/hr

COGENERATION EXAMPLE

Existing – Base Case



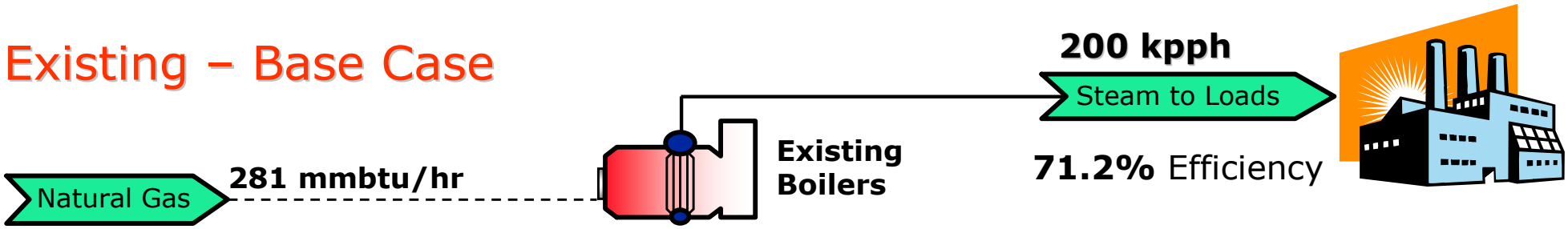
Cogeneration Case



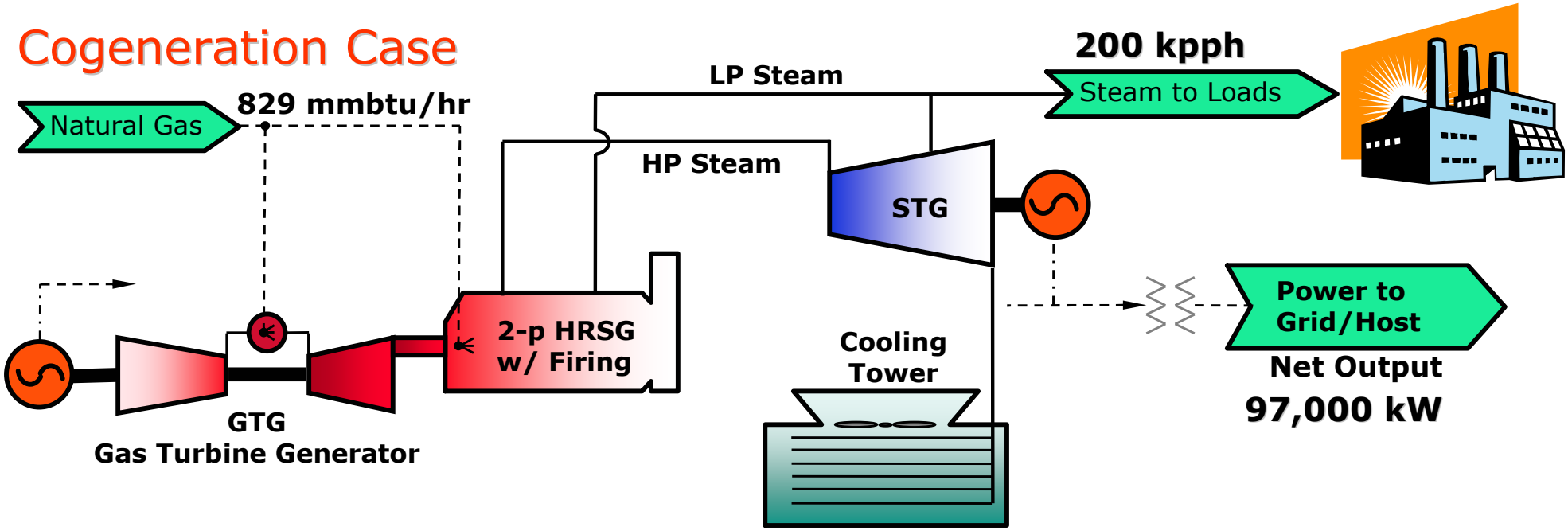
Total Cogeneration Fuel	829 mmbtu/hr
Fuel-Chargeable-to-Steam (FCS)	-281 mmbtu/hr
Fuel-Chargeable-to-Power (FCP)	548 mmbtu/hr

COGENERATION EXAMPLE

Existing – Base Case



Cogeneration Case



Cogeneration or CHP Heat Rate
5328 btu/kW.hr
64% Efficiency

FCP Heat Rate
5650 btu/kW.hr
60.4% Efficiency

TransCanada Energy – Halton Hills Generating Station

Portlands Energy Centre – Toronto

ModernPowerSystems

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Gaz de France's 800 MWe Dunkirk 6 (DK6) plant in northern France, adjacent to Arcelor group's Sollac Atlantique steelworks, can be regarded as France's first large combined cycle gas turbine IPP project.

Generating electricity flexibly using natural gas as well as steelworks (coke oven and blast furnace) gas, the plant is due to be fully operational in early 2005. It will supply electricity to the steelworks as well as selling electricity to the market through the RTE grid.

The basic concept is to improve the competitiveness of the Sollac facility while at the same time giving GdF the opportunity for arbitrage between European gas and electricity markets.

The DK6 plant will burn natural gas in two 165 MW Alstom GT13E2 gas turbines, each coupled with a 345 MWt supplementary fired StandardKessel Lentjes heat recovery steam generator and a 240 MW Alstom steam turbine.

The steelworks gases will be used for supplementary firing in the two vertical gas-flow HRSGs, the biggest such units in the world. Flexibility is a key feature of DK6, with its two independent power trains, bypass stacks and fresh air fans in front of the boilers.

The power plant aims for an economically optimum mix of steelworks and natural gas.

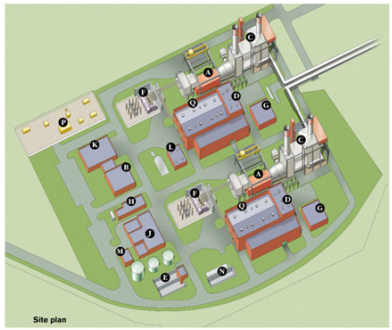
At 400 MWe each train will achieve an efficiency of 50 per cent in combined cycle mode with the 345 MWt of supplementary firing.

If steel mill gas is not available, the output of each train is reduced to 270 MW (with efficiency remaining at 50 per cent). If natural gas is not used, each train can generate 130 MW at 37 per cent efficiency while firing only steel mill gas in the HRSG.

Main technical data

Power plant	
Type	Combined cycle with supplementary firing
Integrated plant design point (°C)	10
Gross electrical power (MW)	800
Gross efficiency (%)	48
Fuel	Natural gas (GT), Natural gas, blast furnace gas, Coke oven gas (HRSG)
Gas turbine	
Number of units	2
Supplier	ALSTOM
Type	GT13E2
Shaft speed (rpm)	3000
Compression ratio	14.6:1
Number of compressor stages	21
Number of turbine stages	5
Exhaust gas temperature (°C)	524
Exhaust mass flow (kg/s)	532
Low NO_x burner type	EV
NO_x emissions (vppm)	<25ppm
Steam turbine	
Number of units	2
Supplier	ALSTOM
Type	3 pressure reheat and condensing Reaction type - double flow LP lateral
Configuration	
Shaft speed (rpm)	3000

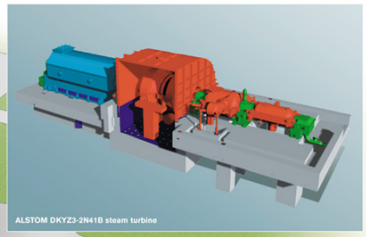
Heat recovery steam generator	
Number of units	2
Supplier	StandardKessel Lentjes
Type	Vertical - 1 pressure reheat - supplementary firing - fresh air
HP steam	
Mass flow (kg/s)	148
pressure (bar)	144
Temperature (°C)	565
IP steam - reheat	
Mass flow (kg/s)	147
Operating pressure (bar)	50
Temperature (°C)	565
Gas turbine generator	
Number of units	2
Supplier	ALSTOM
Type	Synchronous, air-cooled
Rated output (MVA)	198
Power factor	0.85
Frequency (Hz)	50
Voltage (kV)	15.7
Steam turbine generator	
Number of units	2
Supplier	ALSTOM
Type	Synchronous, air-cooled
Rated output (MVA)	285
Power factor	0.85
Frequency (Hz)	50
Voltage (kV)	18



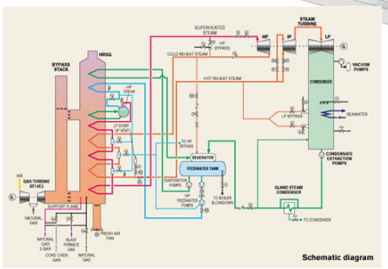
Site plan

Key - site plan

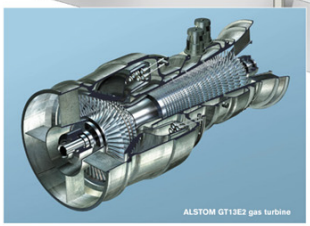
A Gas turbine
B Control building
C Heat recovery steam generator
D Feedwater tank + feedwater pump building
E Industrial water recovery pit
F Transformer
G Unit electrical building
H Emergency diesel generator + common electrical building
J Water treatment plant
K Workshop & warehouse
L Air compressor station
M Fire fighting pump house
N Storm water basin
P Natural gas expansion station (GdF)
Q Steam turbine building



ALSTOM DKYZ3-2N41B steam turbine



Schematic diagram



ALSTOM GT13E2 gas turbine

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Key

1 GT13E2 gas turbine
2 GT electrical generator - TEWAC
3 Low pressure steam turbine
4 High pressure/intermediate pressure steam turbine
5 Water cooled condenser
6 Air intake for GT
7 Main transformer
8 Heat recovery steam generator
9 Exhaust stack
10 Generator circuit breaker
11 Bus duct
12 Overhead crane
13 HRSG diverter dampers
14 HRSG burners
15 Fresh air fan
16 ST electrical generator - TEWAC
17 Feedwater tank
18 Bypass stack
19 Blast furnace gas pipe

GTAA Cogen – Toronto Airport

West Windsor Power – Windsor

Goreway Station Power – Toronto

East Windsor Cogeneration Centre – Windsor

Before

After