GTEN 2019 Symposium

October 21-23, 2019 | Banff, Alberta

Day 1 – Training Session #2
Cogeneration, Combined-Cycle and Power Plant Basics

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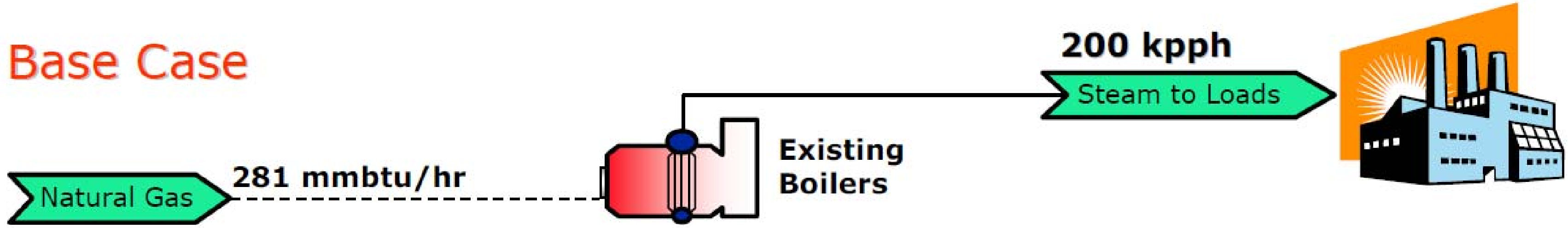
A brief introduction to the basics of cogeneration, combined-cycle and power plants, utilizing gas turbines and related equipment

Presented at the Gas Turbines Energy Network (GTEN) 2019 Symposium
Banff, Alberta, Canada - October 2019

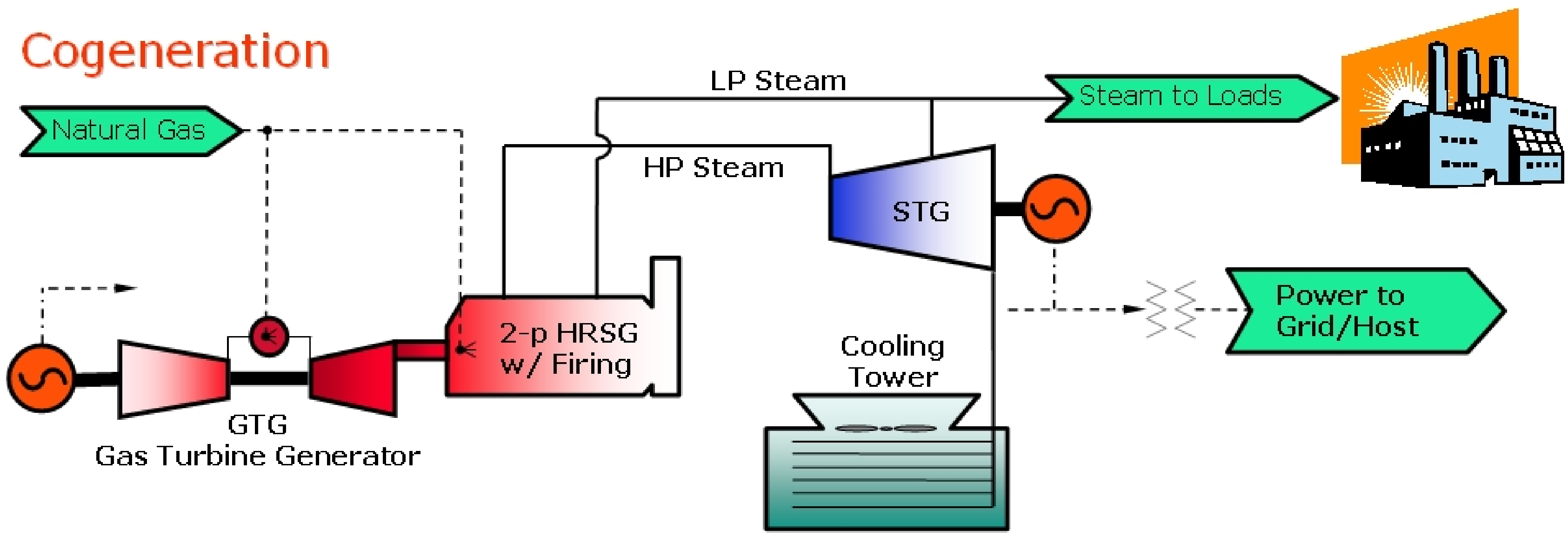
SHP or SEPARATE HEAT-AND-POWER:

The "on-site heat/cooling production for industrial processes or space heating / cooling, and electricity purchase from the grid (large-scale power plants)."



CHP / COGENERATION:

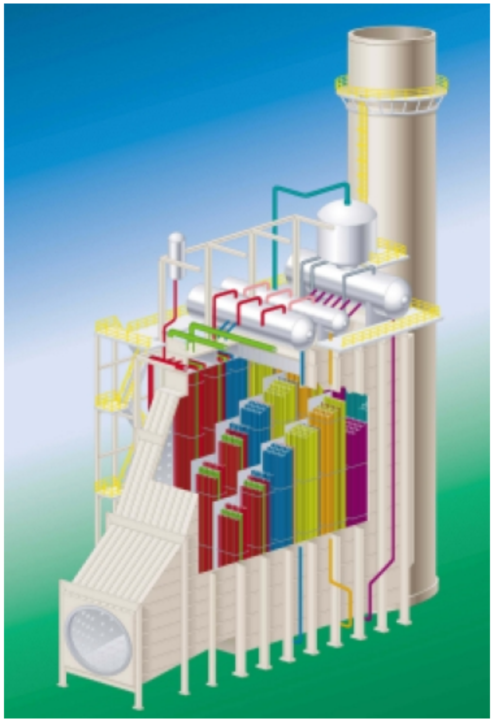
"The simultaneous production of two or more forms of useful energy (e.g. heat / cooling and electricity) from a single fuel source, usually on-site or nearby"

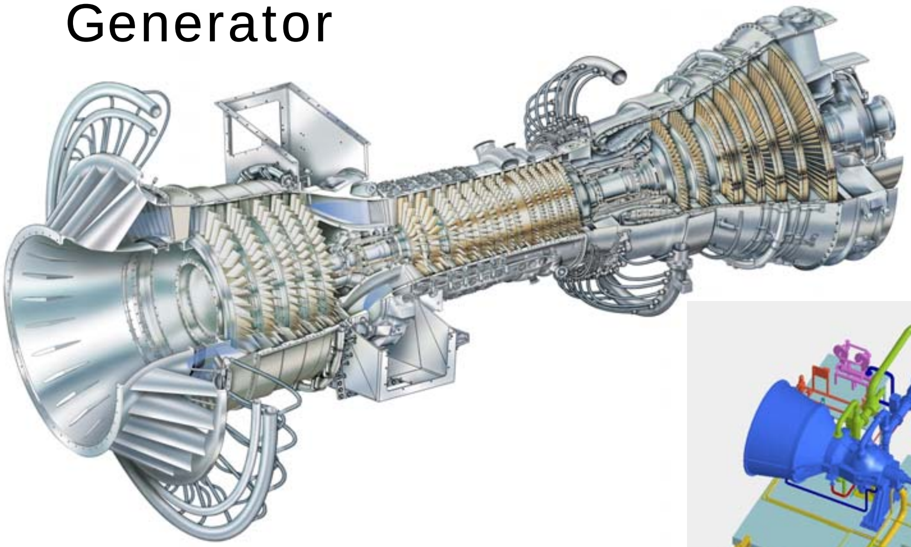


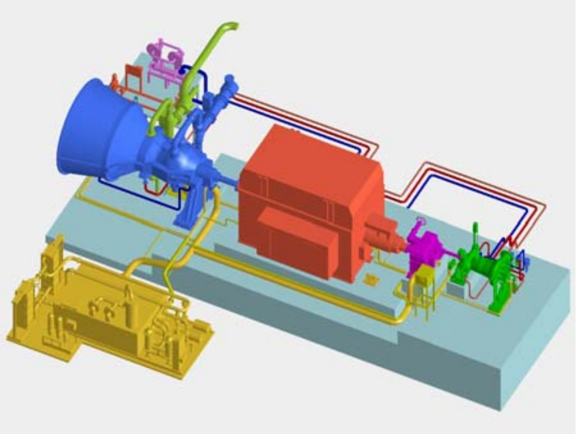
MAJOR EQUIPMENT

Usually associated with Cogeneration / CHP cycles

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







HEAT RECOVERY STEAM GENERATORS - HRSG

The high-temperature, high-flow exhaust of gas turbines can be utilized to make steam (or hot-water or to heat thermal oils) via a Heat Recovery Steam Generator (HRSG).

The HRSG steam produced can be used for:

- Directly for process, i.e. a combined-heat-and-power (**CHP**) or **cogeneration** process.
- Integration into a **combined-cycle** power plant, which makes electrical power via the gas turbine and a steam turbine.

There are many types and variations of HRSGs, including:

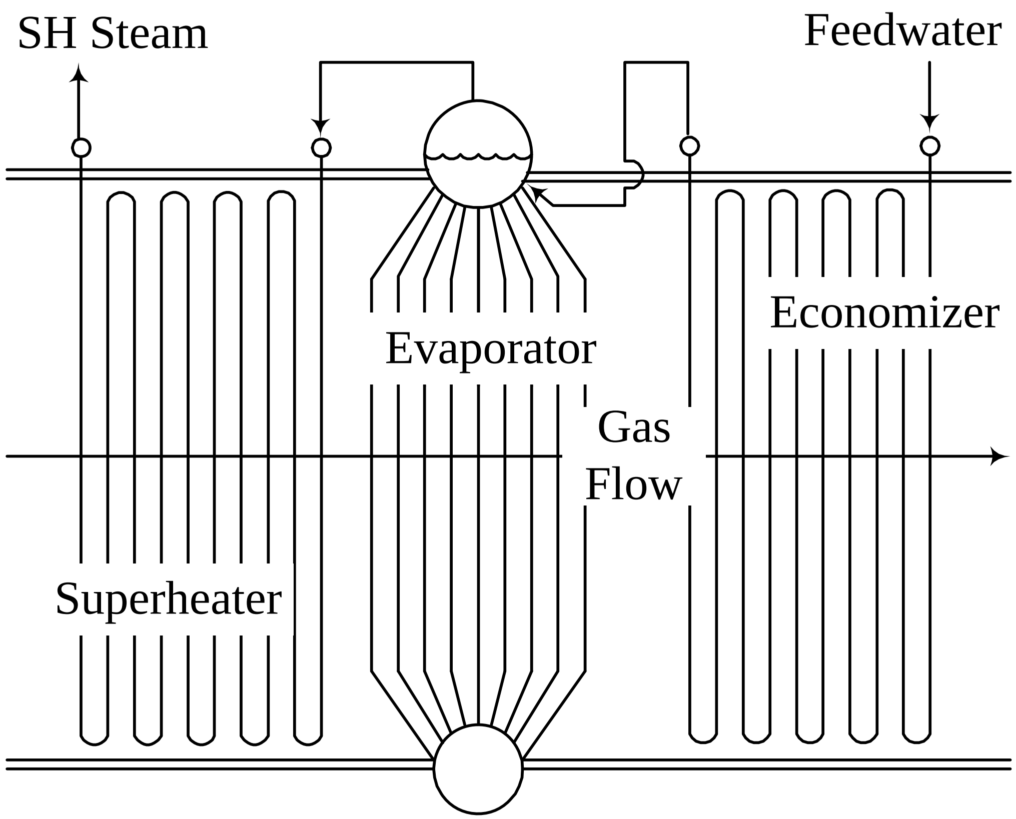
- **Single-Pressure HRSG** – making either saturated steam or superheated steam.
- **Dual-Pressure** – making steam at 2 pressure levels (high & lower pressures)
- **Triple-Pressure** – making steam at 3 different pressure levels (HP, IP & MP or LP)
- **Reheat HRSGs** – a multi-pressure HRSG where high pressure steam is re-introduced to the HRSG after it has partially expanded through a steam turbine, and is then re-heated towards the original high-pressure steam's temperature.
- **Firing** – HRSGs can be further classified by whether they are duct-fired or unfired. Gas turbines have sufficient oxygen in their exhausts to allow the introduction and combustion of additional fuel prior to the steam generation banks. Duct-firing increases steam production.
- **Fresh-Air Firing** – can be incorporated to allow the HRSG to behave like a boiler if the GTG is not operating.

Typical HRSG Configuration (Drum-Type)

The gas turbine exhaust gases flow through:

- **Superheater** section – adds sensible heat (temperature) to saturated steam.
- **Evaporator** section – produces only saturated steam (at constant temperature).
- **Economizer** section – adds sensible heat (temperature) to incoming feedwater.

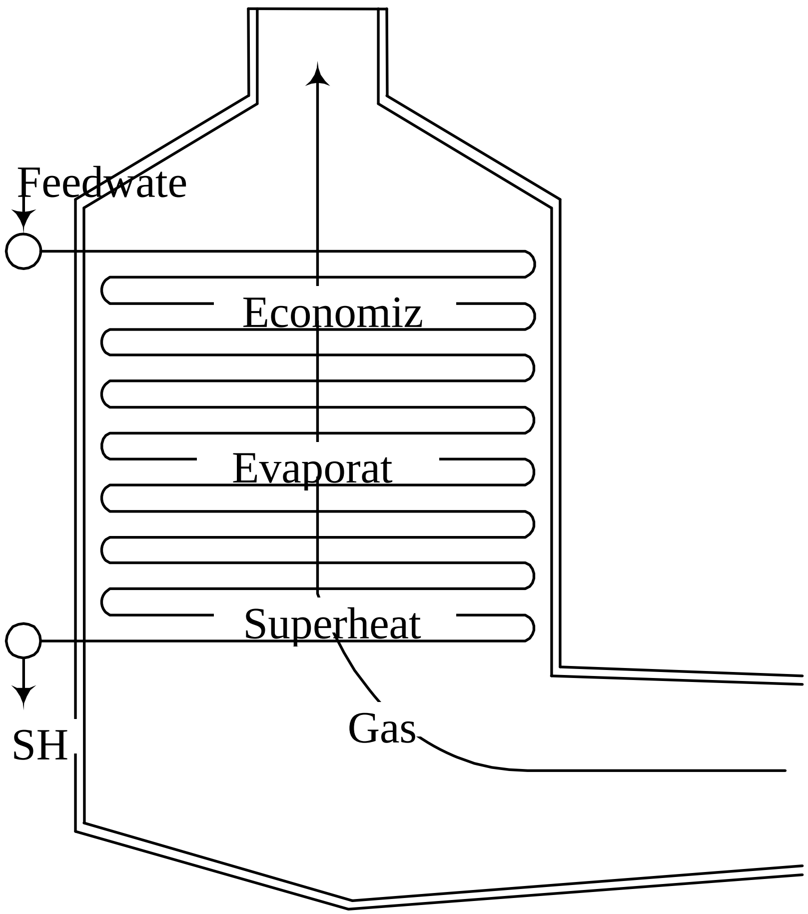
The feedwater/steam flows in reverse to the turbine exhaust gases.



Once-Through Steam Generator (No Drums)

OTSGs were previously manufactured by Innovative Steam Technologies (IST) in Cambridge, Ontario. OTSGs can run "dry" meaning no water/steam in the tube banks.

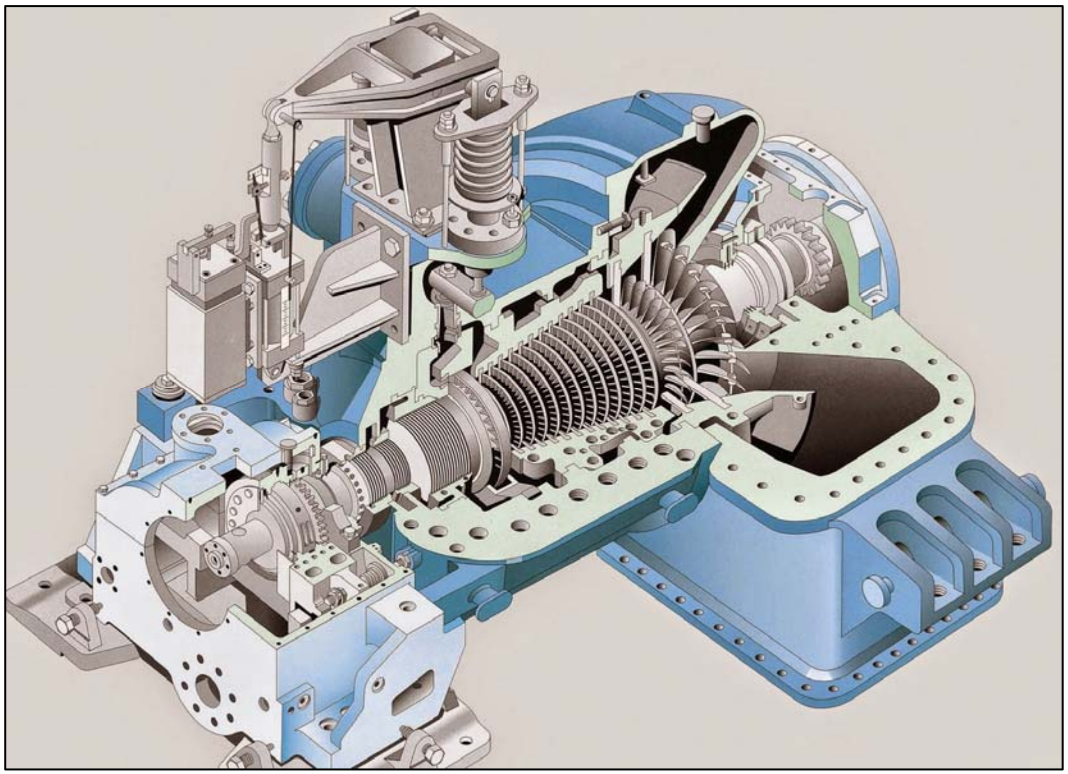
An OTSG variation producing wet saturated steam is used for Enhanced Oil Recovery (EOR) in the Albertan Oil Sands regions.

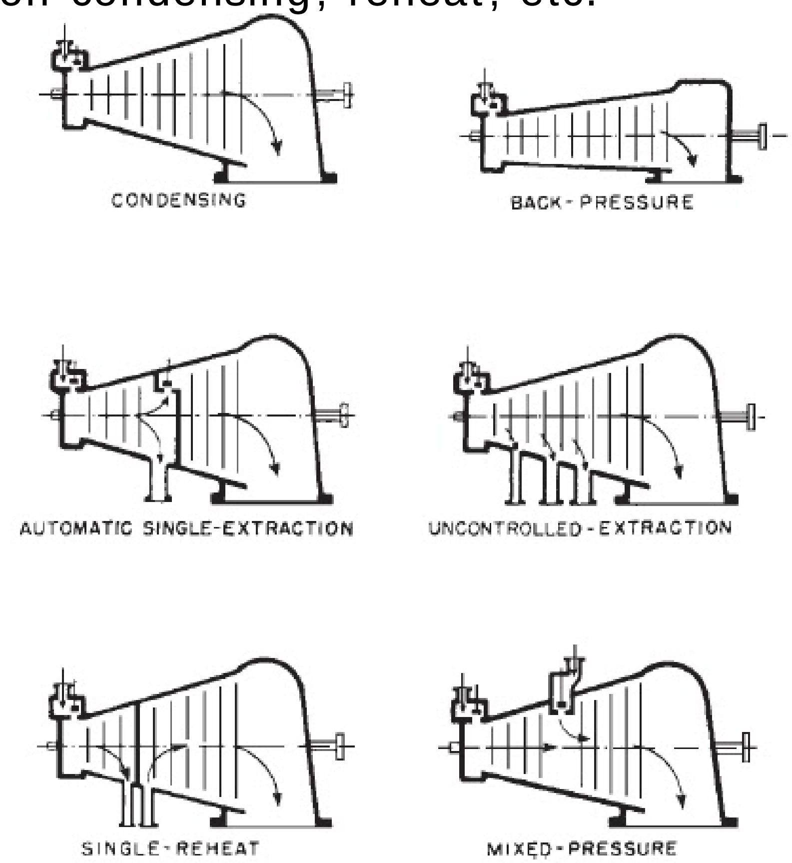


STEAM TURBINES

Steam produced in the HRSG section(s) can be utilized in a steam turbine to produce additional electrical or mechanical power.

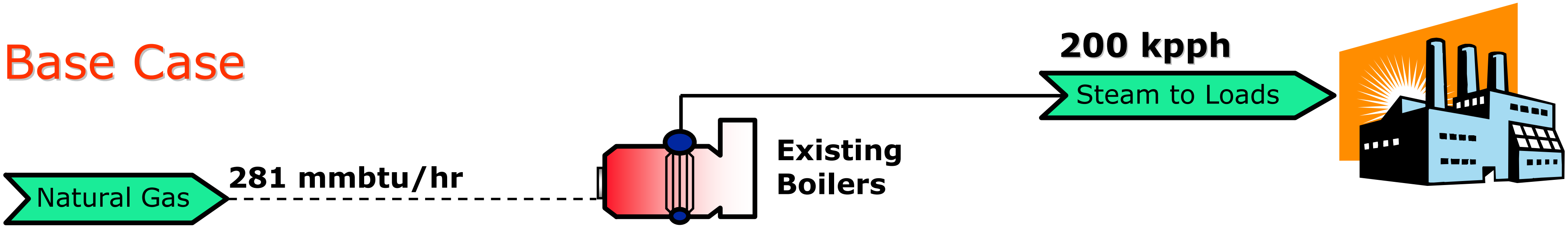
- **Backpressure** steam turbines make electricity & release steam to process.
- **Condensing** steam turbines make electricity only.
- **Extraction** steam turbines make electricity & release steam to process.
- Variations include extraction-condensing; admission-condensing; reheat; etc.





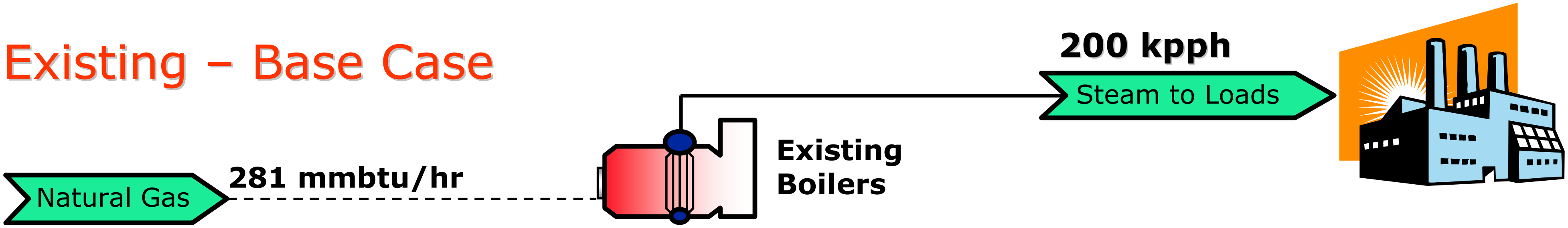
COGENERATION EXAMPLE

Base Case



COGENERATION EXAMPLE

Existing – Base Case



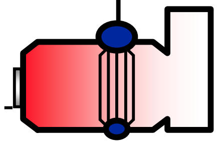
Cogeneration Case

COGENERATION EXAMPLE

Existing – Base Case

Natural Gas

281 mmbtu/hr



Existing Boilers

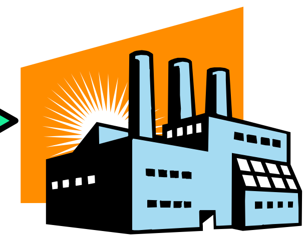
200 kpph

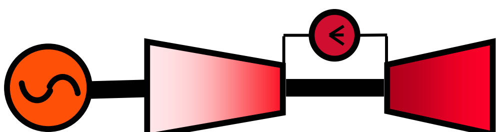
Steam to Loads

Cogeneration Case

200 kpph

Steam to Loads

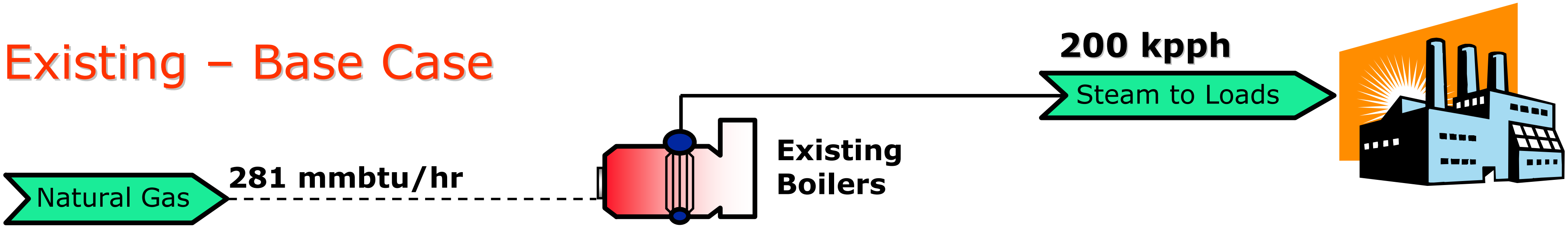




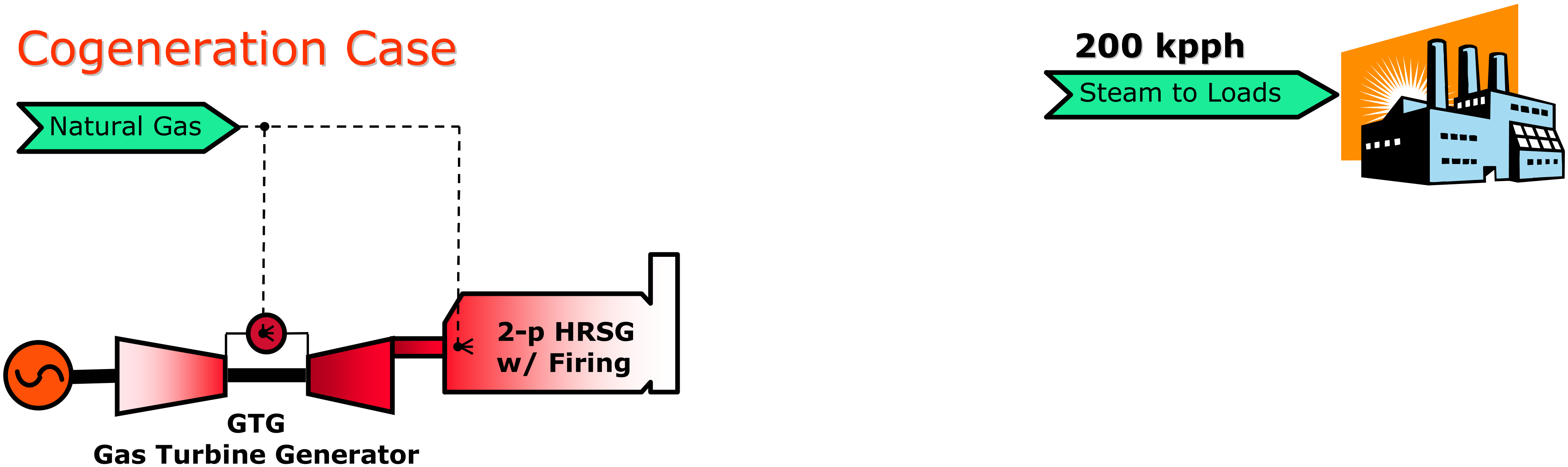
GTG
Gas Turbine Generator

COGENERATION EXAMPLE

Existing – Base Case

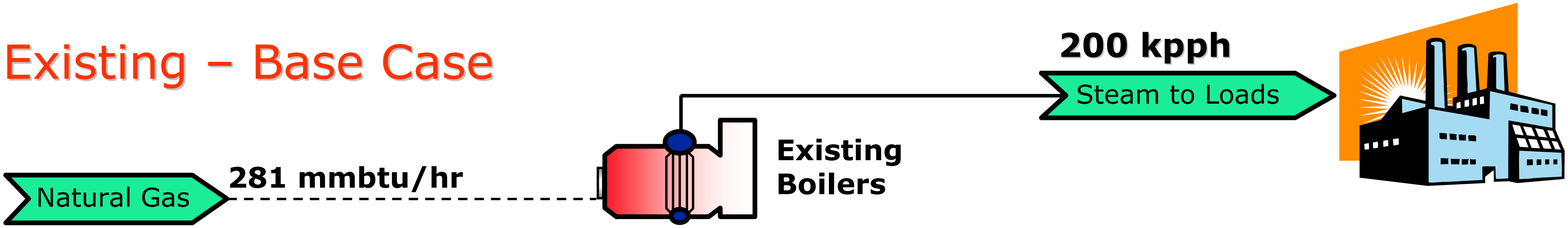


Cogeneration Case

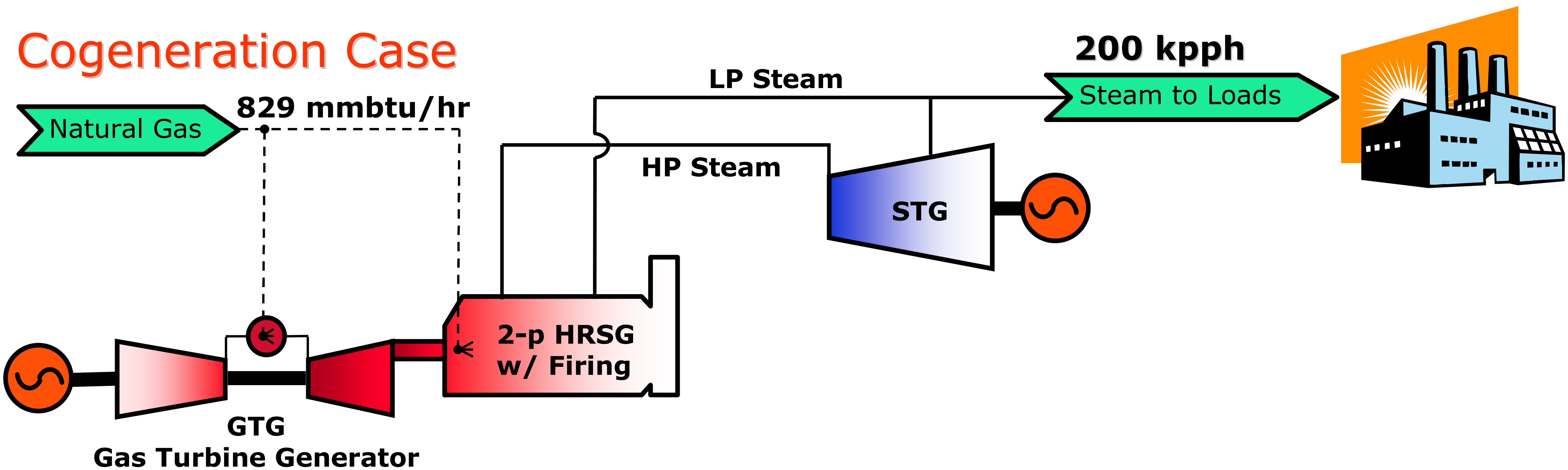


COGENERATION EXAMPLE

Existing – Base Case

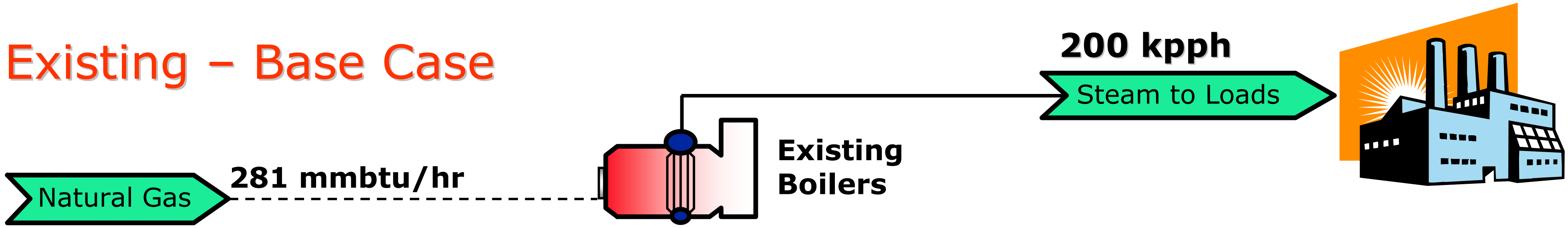


Cogeneration Case

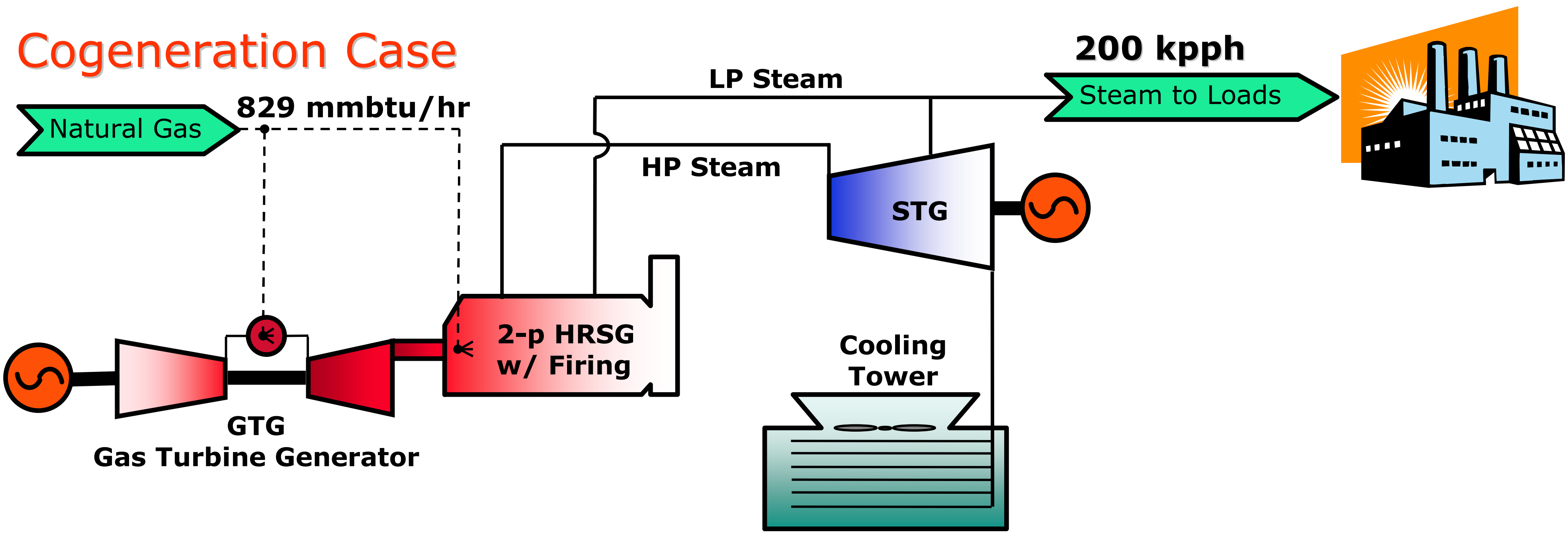


COGENERATION EXAMPLE

Existing – Base Case

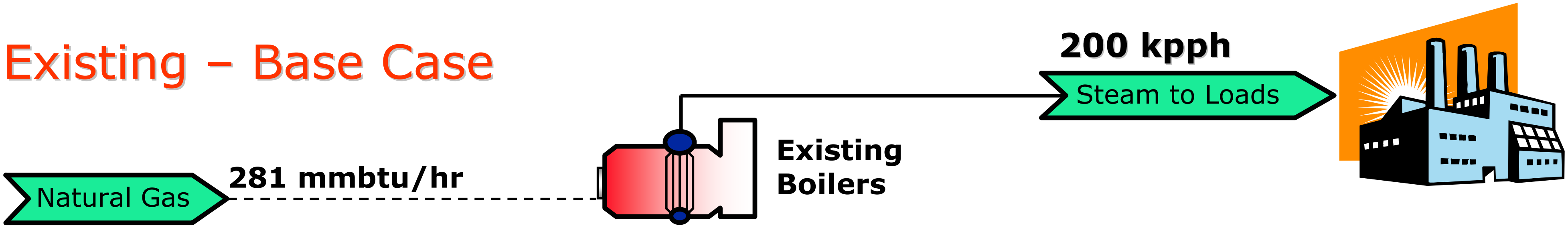


Cogeneration Case

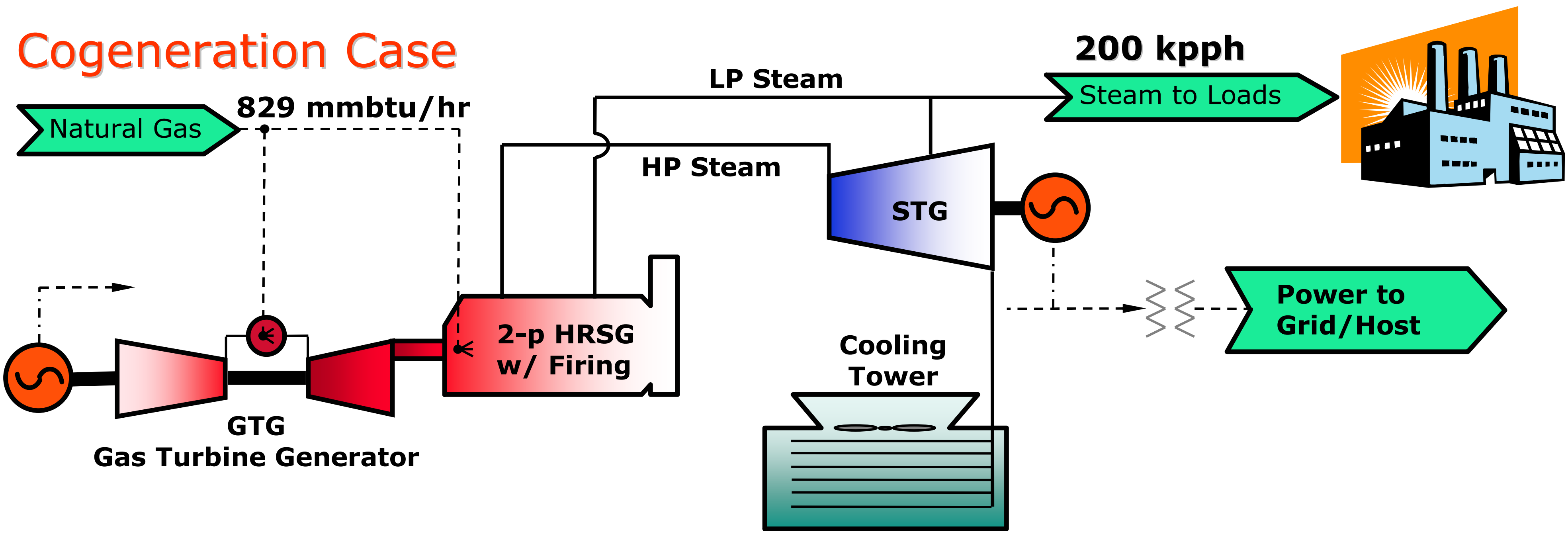


COGENERATION EXAMPLE

Existing – Base Case

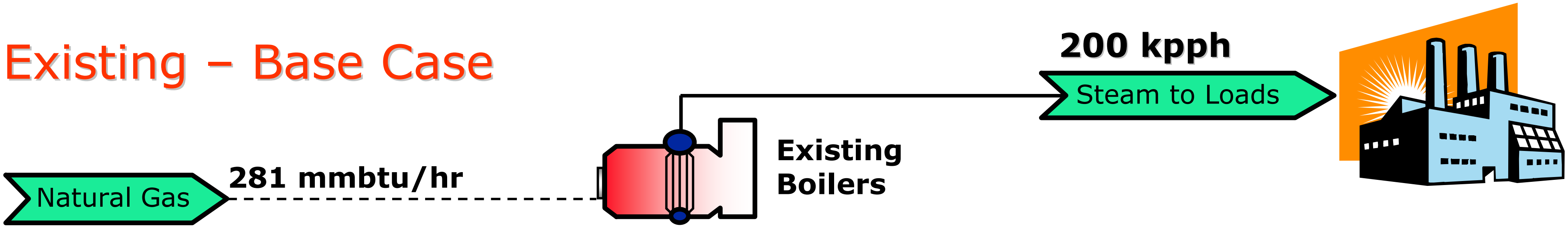


Cogeneration Case

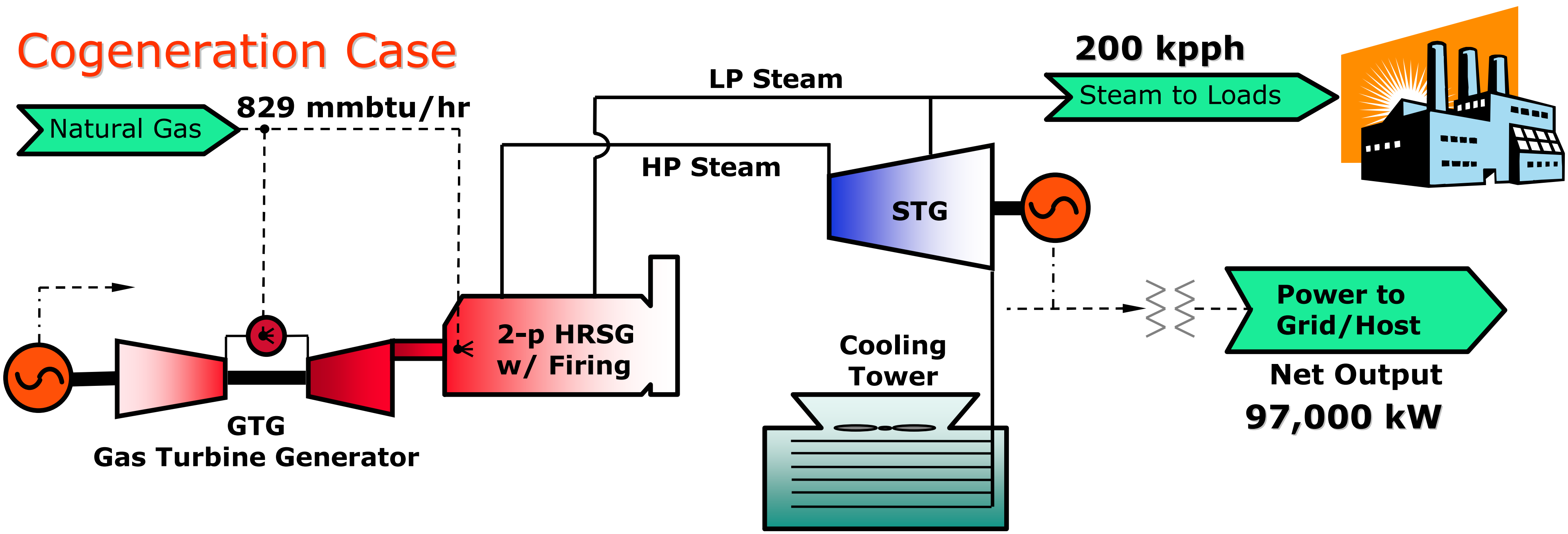


COGENERATION EXAMPLE

Existing – Base Case

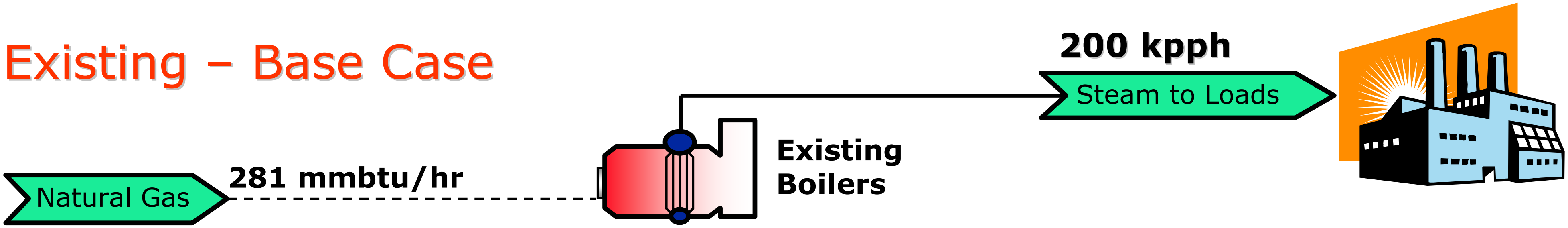


Cogeneration Case

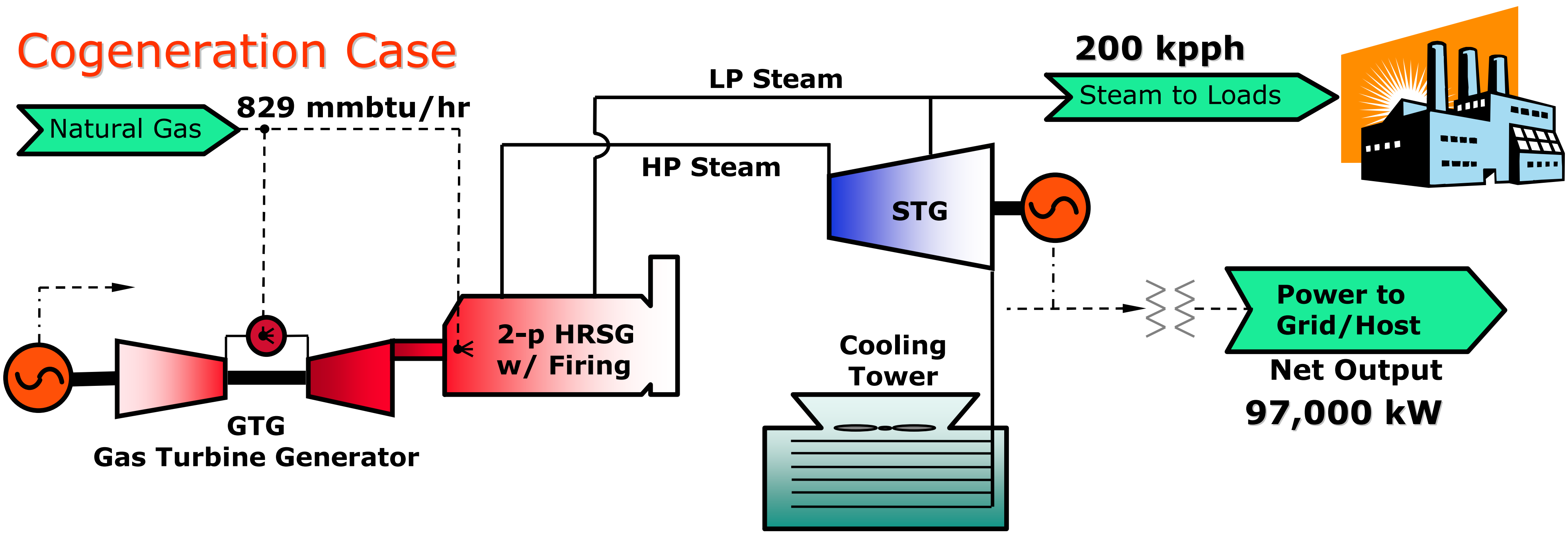


COGENERATION EXAMPLE

Existing – Base Case



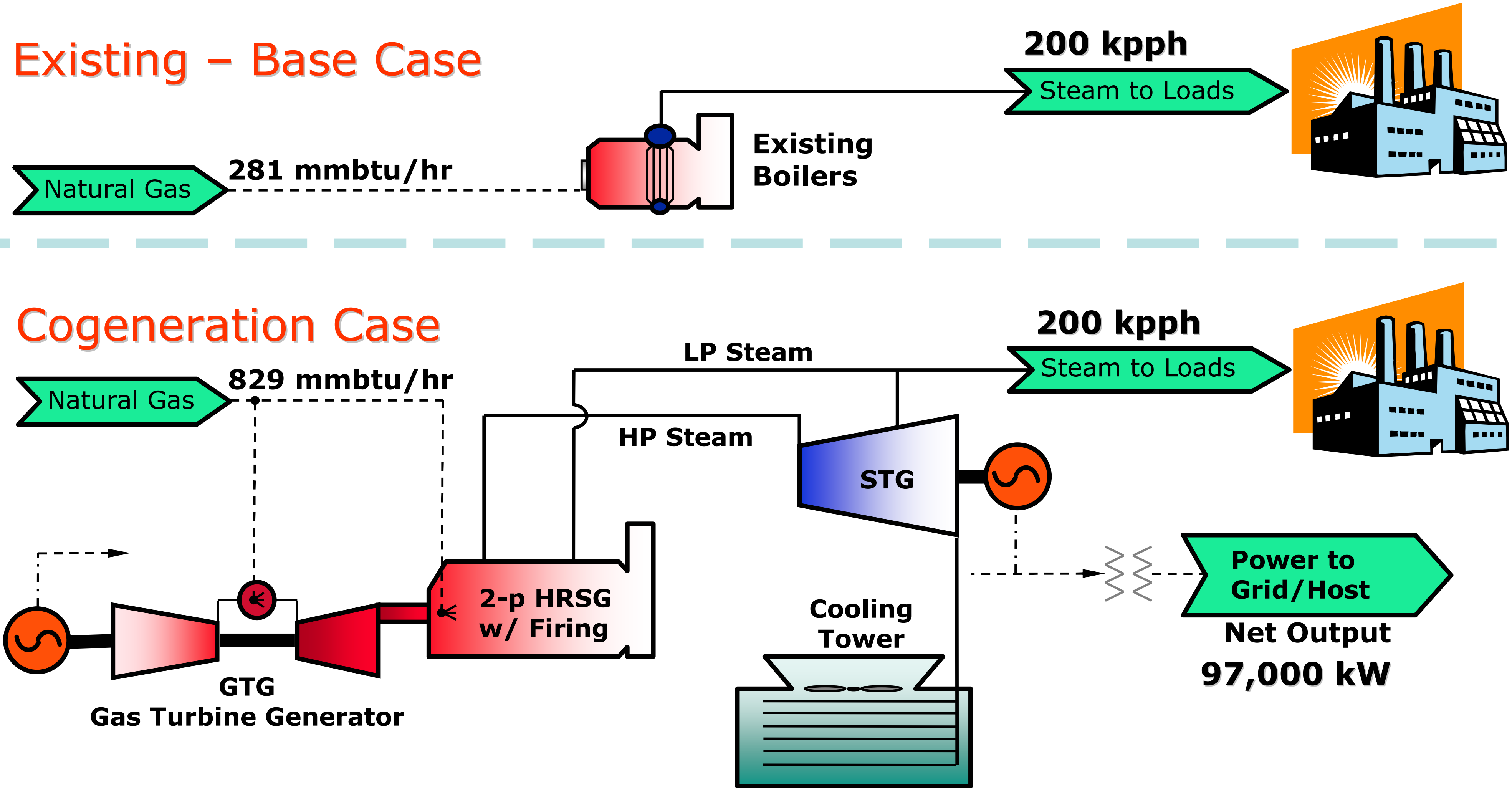
Cogeneration Case



Cycle Inputs:
Fuel: 829 mmbtu/hr

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

COGENERATION EXAMPLE



Cycle Inputs:
Fuel: 829 mmbtu/hr

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

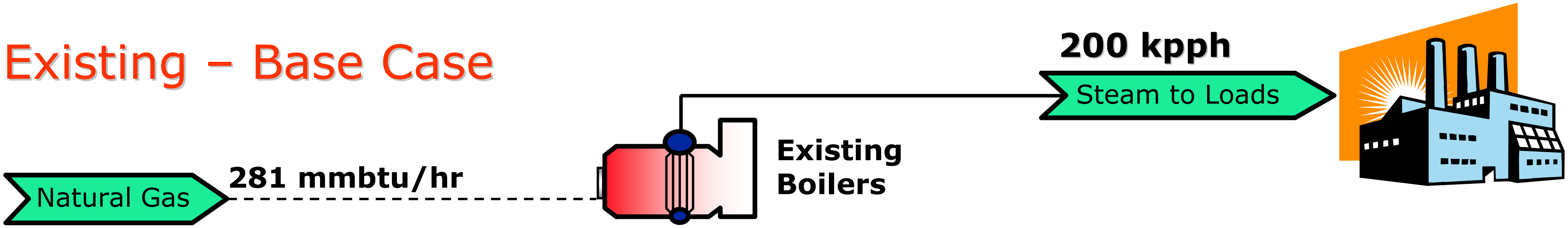
Cogeneration or CHP Efficiency

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

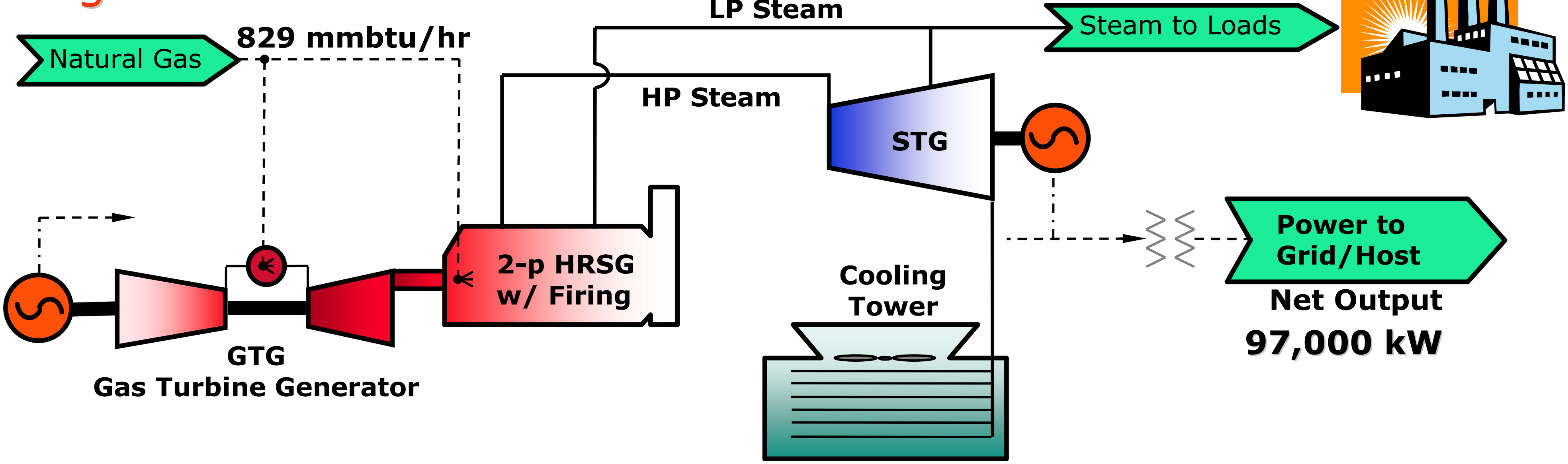
= 64% (or a Heat Rate of **5328** btu/kW.hr)

COGENERATION EXAMPLE

Existing – Base Case



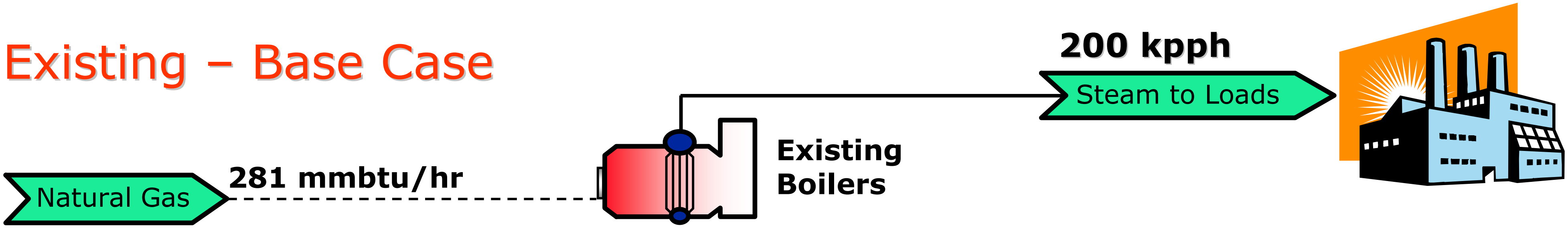
Cogeneration Case



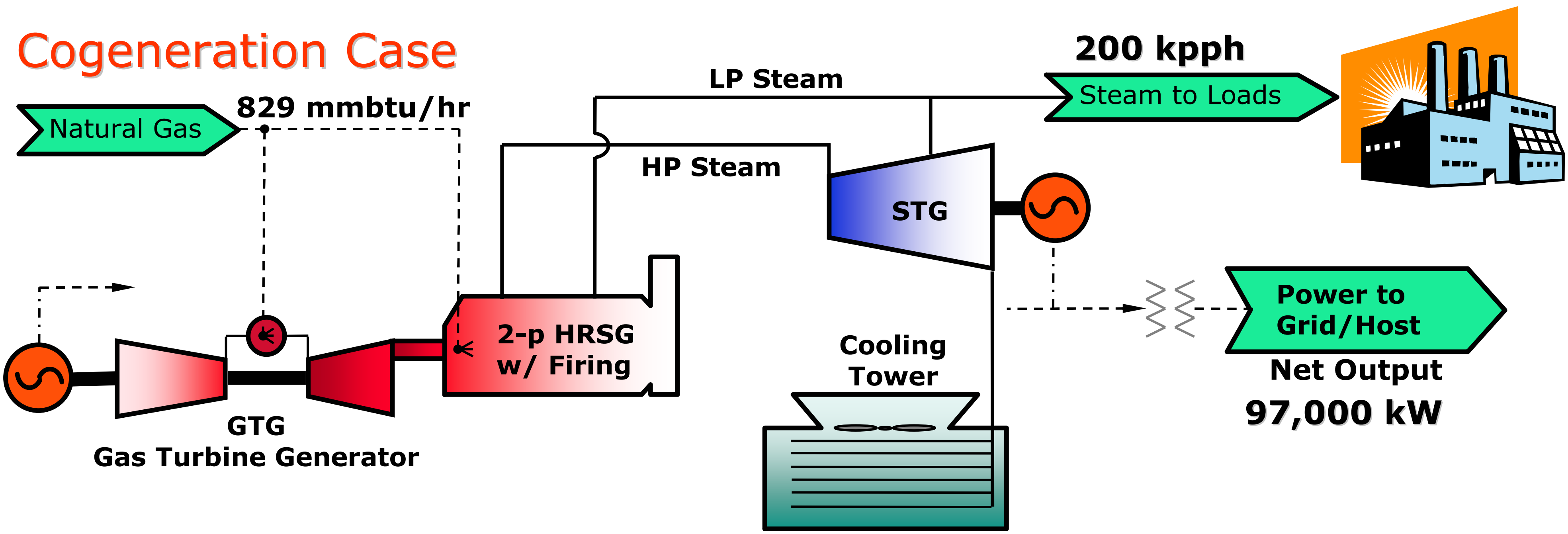
Total Cogeneration Fuel 829 mmbtu/hr

COGENERATION EXAMPLE

Existing – Base Case

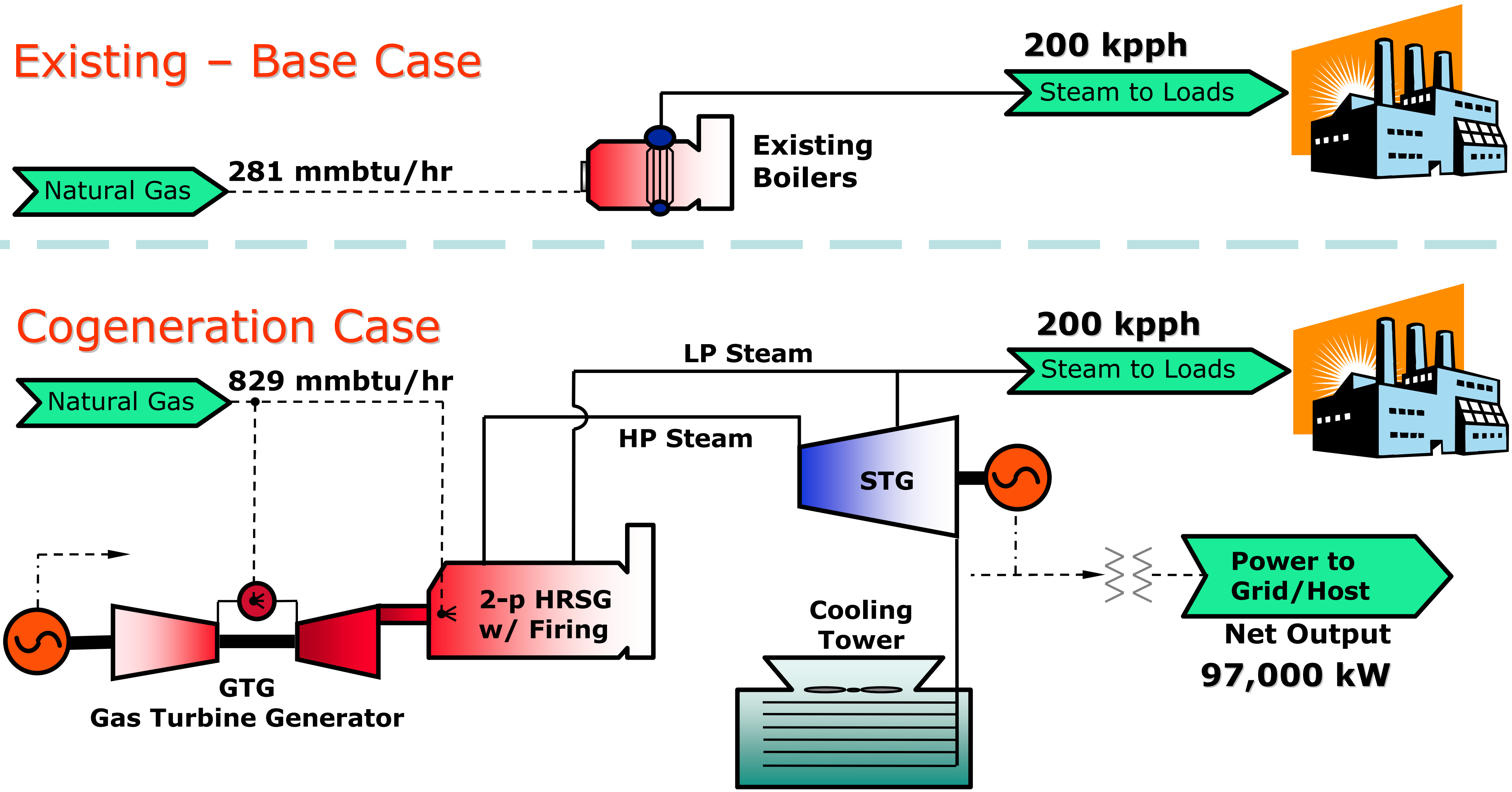


Cogeneration Case



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

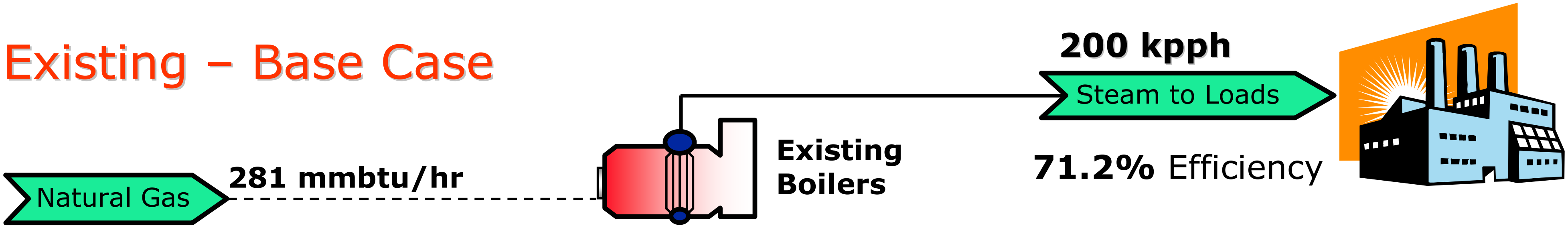
COGENERATION EXAMPLE



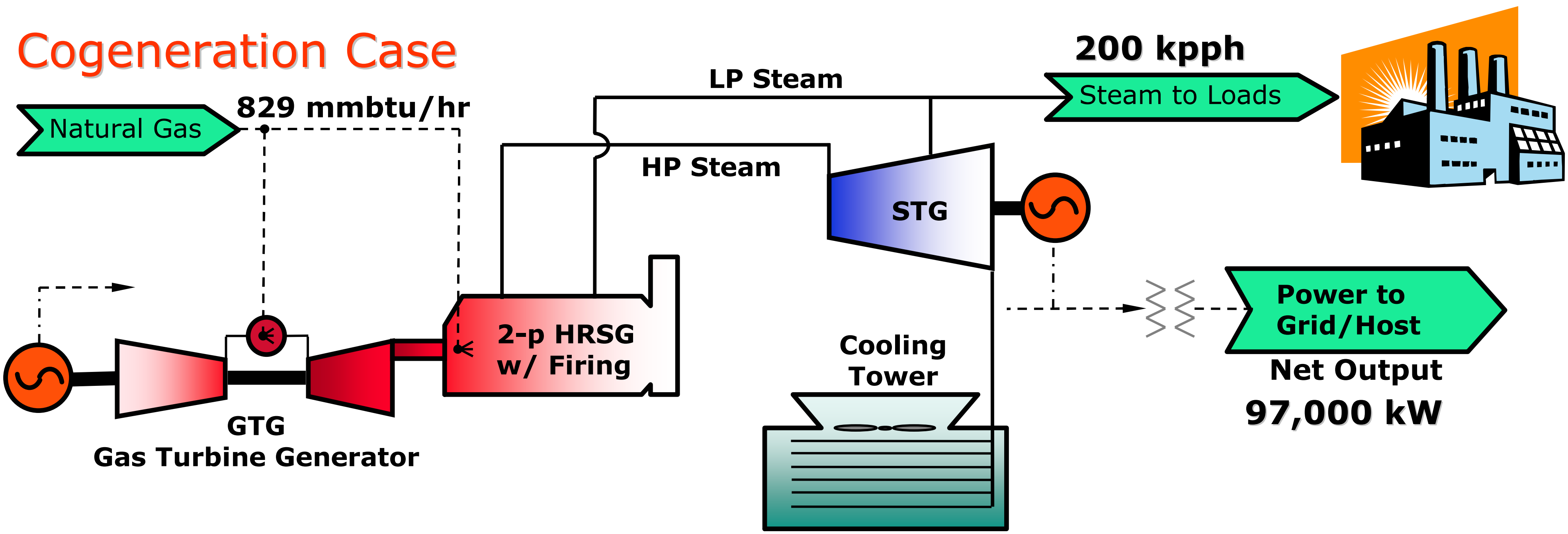
Total Cogeneration Fuel	829 mmbtu/hr
Fuel-Chargeable-to-Steam (FCS)	-281 mmbtu/hr
Fuel-Chargeable-to-Power (FCP)	548 mmbtu/hr

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

3.5 MW Gas Turbine & HRSG
London Health Sciences Centre, Ontario

4.5 MW Gas Turbine & HRSG
Campbell's Soup – Toronto Ontario

55 MW Gas Turbine & HRSG – Whitby Cogeneration

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

GTAA Cogen – Toronto Airport

East Windsor Cogeneration Centre – Windsor

Before

After

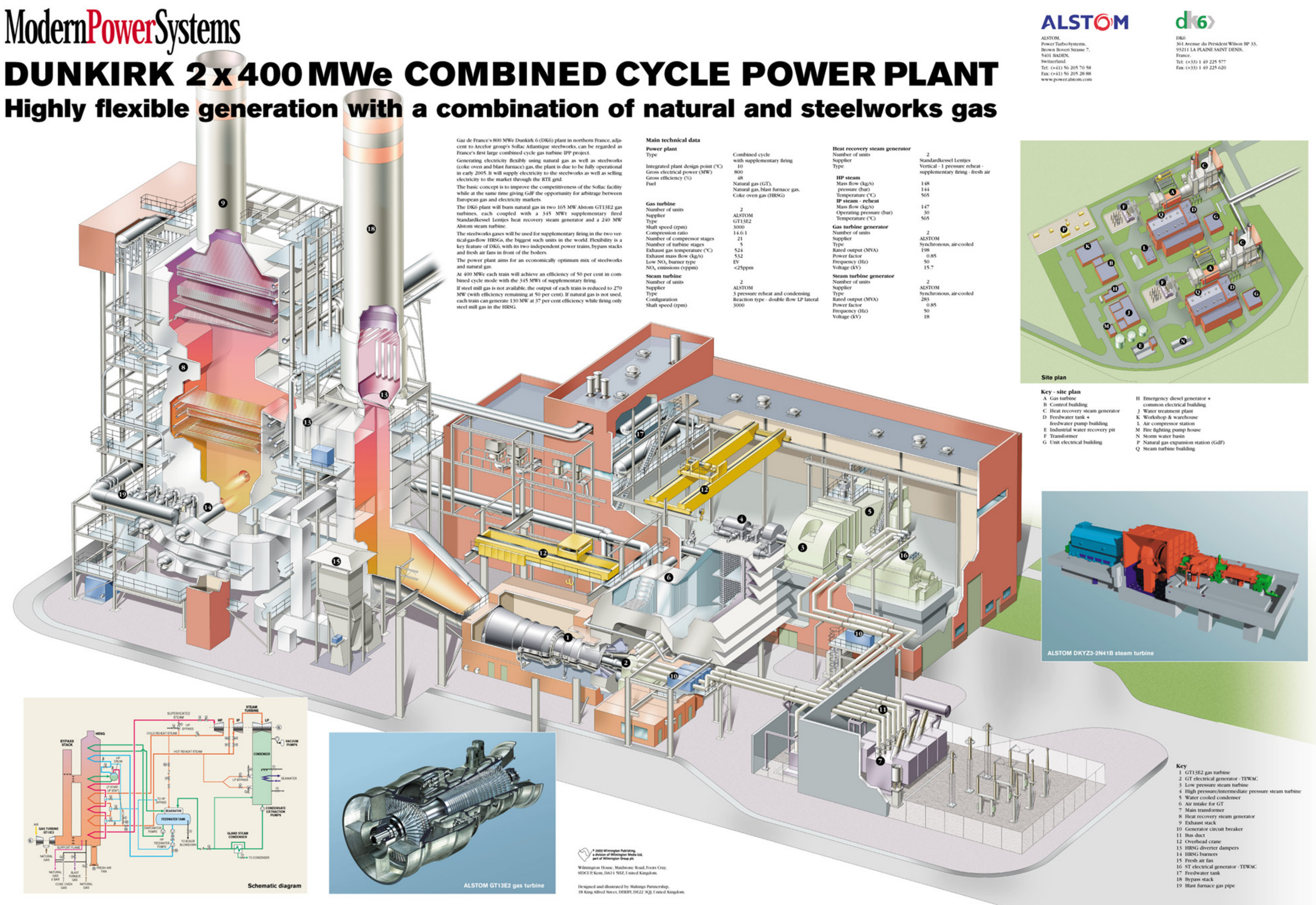
Combined-Cycle Cogeneration – Lake Superior Power

West Windsor Power – Windsor

TransCanada Energy – Halton Hills Generating Station

Goreway Station Power – Toronto

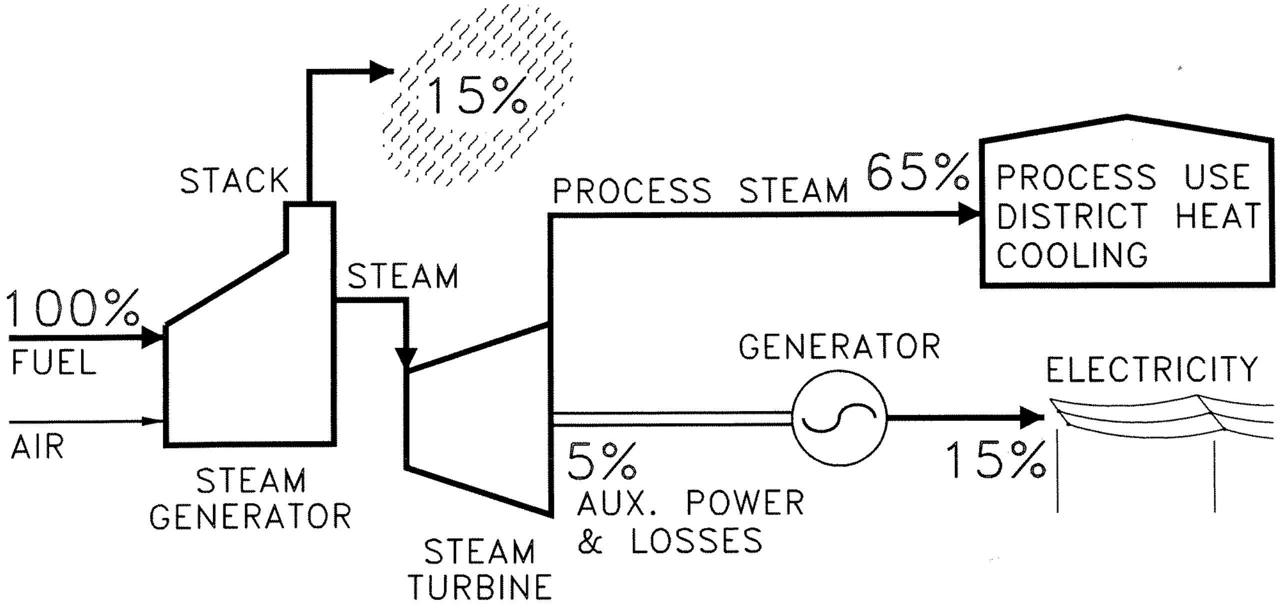
Portlands Energy Centre – Toronto


ModernPowerSystems
DUNKIRK 2 x 400 MWe COMBINED CYCLE POWER PLANT
Highly flexible generation with a combination of natural and steelworks gas
ALSTOM
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 NOx burner type: EV
NOx emissions (vppm): <25ppm
Steam turbine
Number of units: 2
Supplier: ALSTOM
Type: 3 pressure reheat and condensing
Configuration: Reaction type - double flow LP lateral
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): 30
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): 283
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
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
Schematic diagram
ALSTOM GT13E2 gas turbine

FUEL → ELECTRICITY → PROCESS HEAT

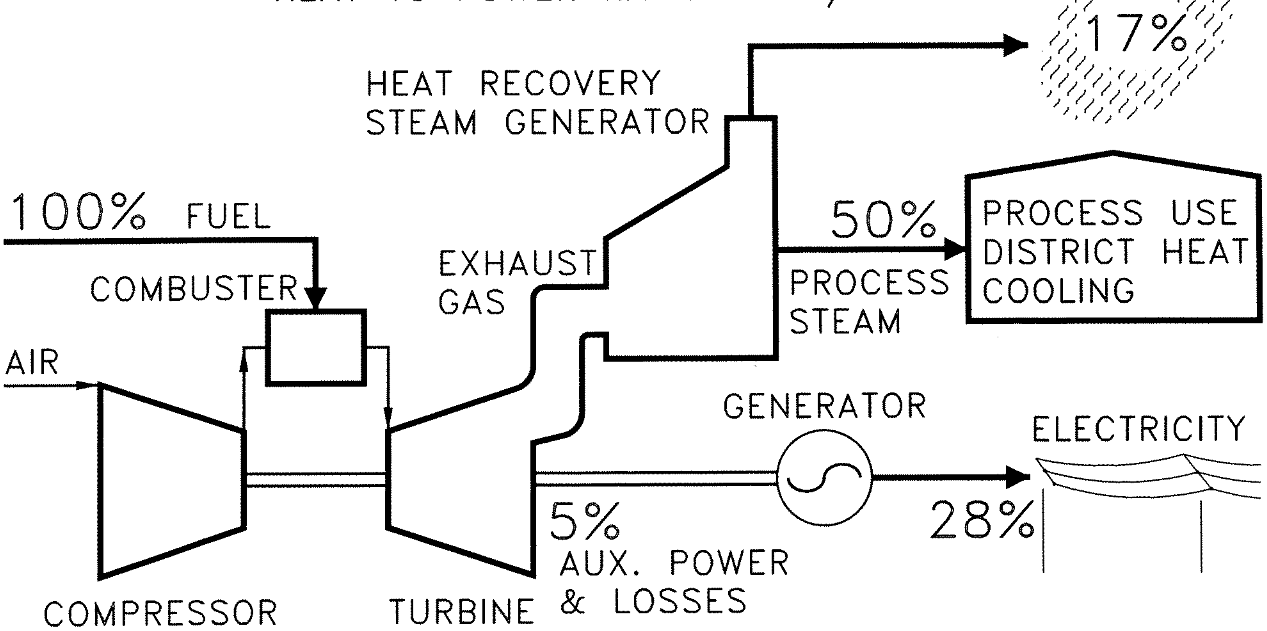
A. STEAM GENERATOR/STEAM TURBINE

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

GRYPHON
INTERNATIONAL ENGINEERING SERVICES INC.

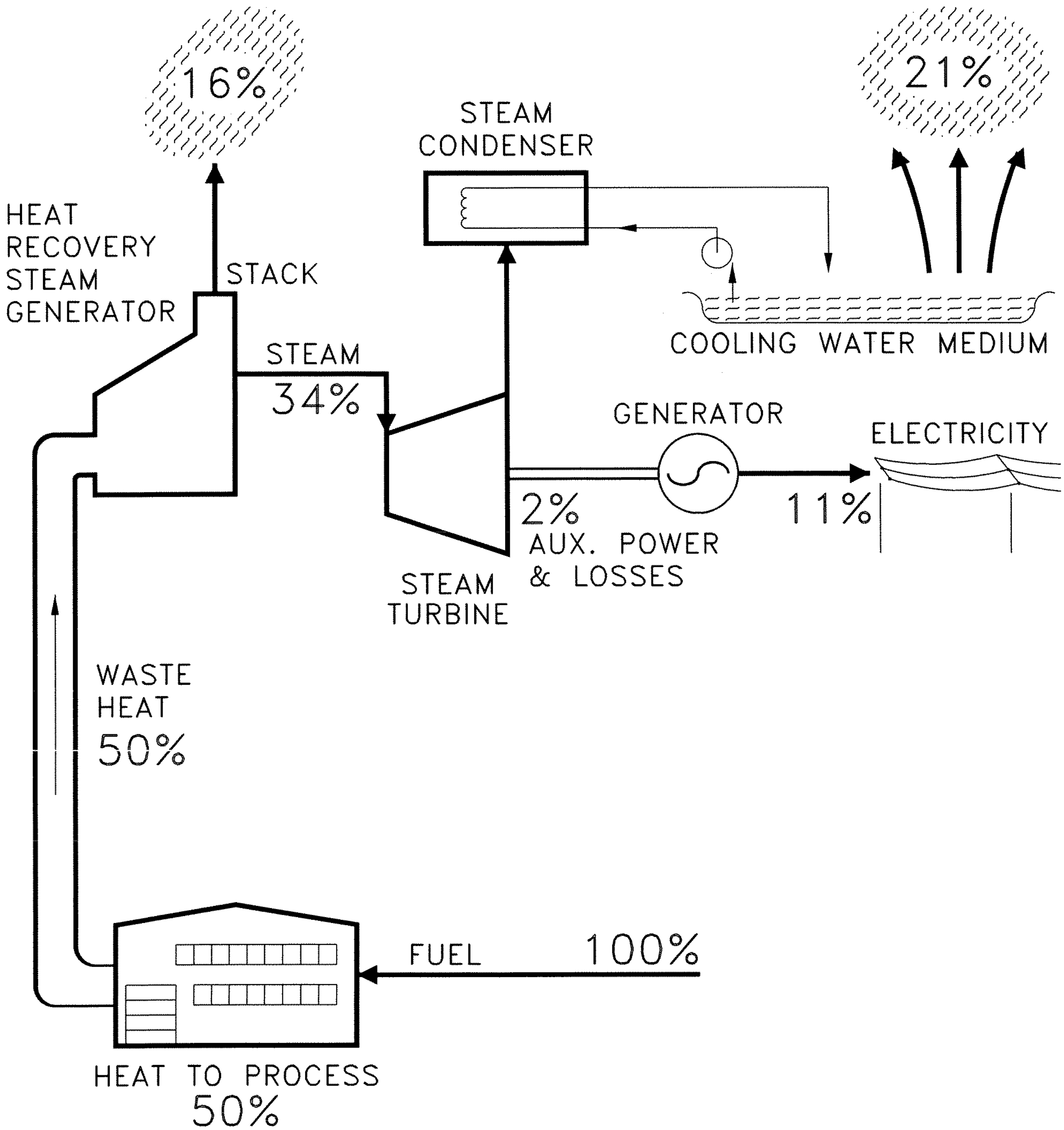
TOPPING CYCLES

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

GRYPHON
INTERNATIONAL ENGINEERING SERVICES INC.

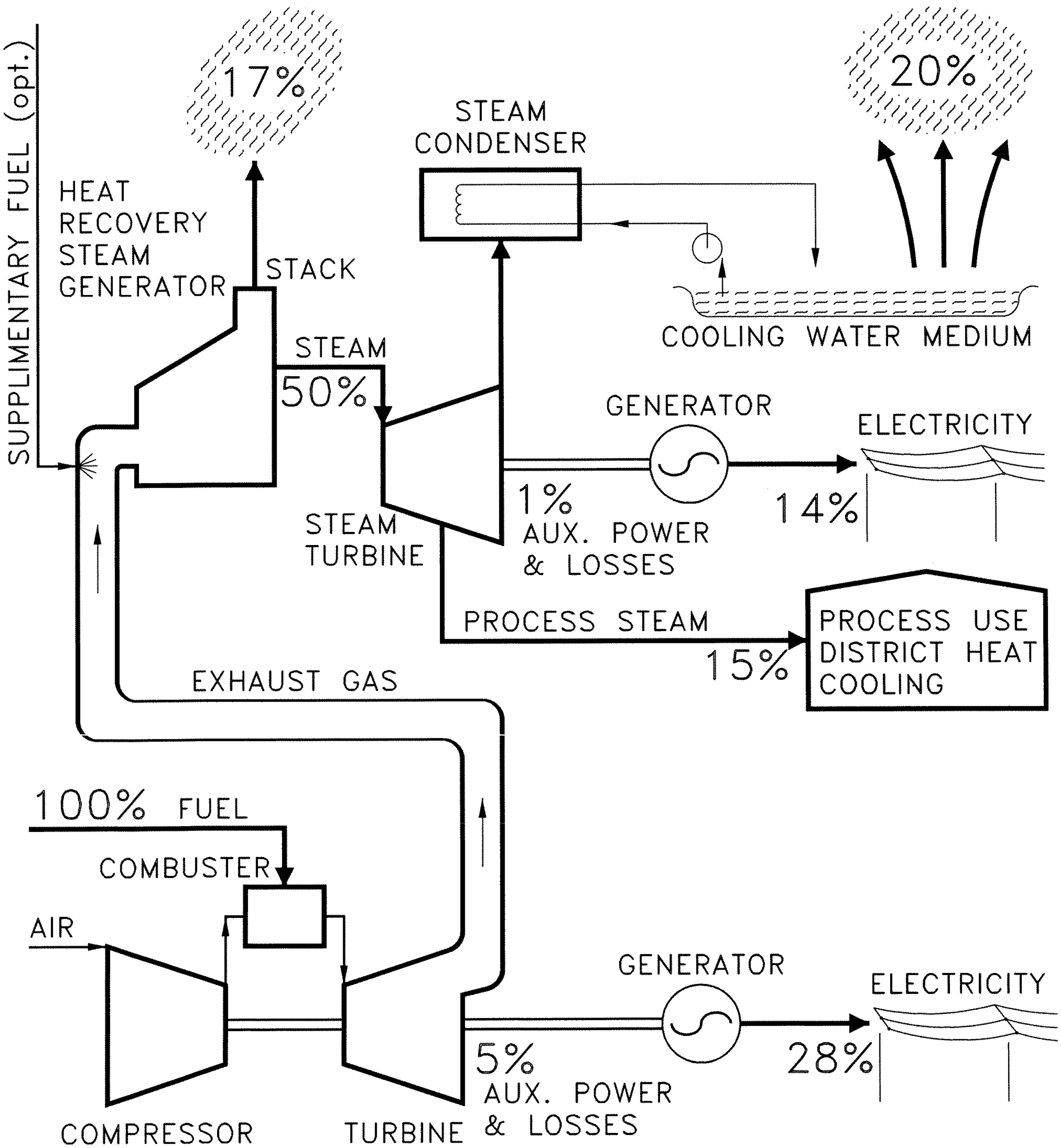
BOTTOMING CYCLE

JAN. 2000	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



ALL EFFICIENCIES ARE HHV

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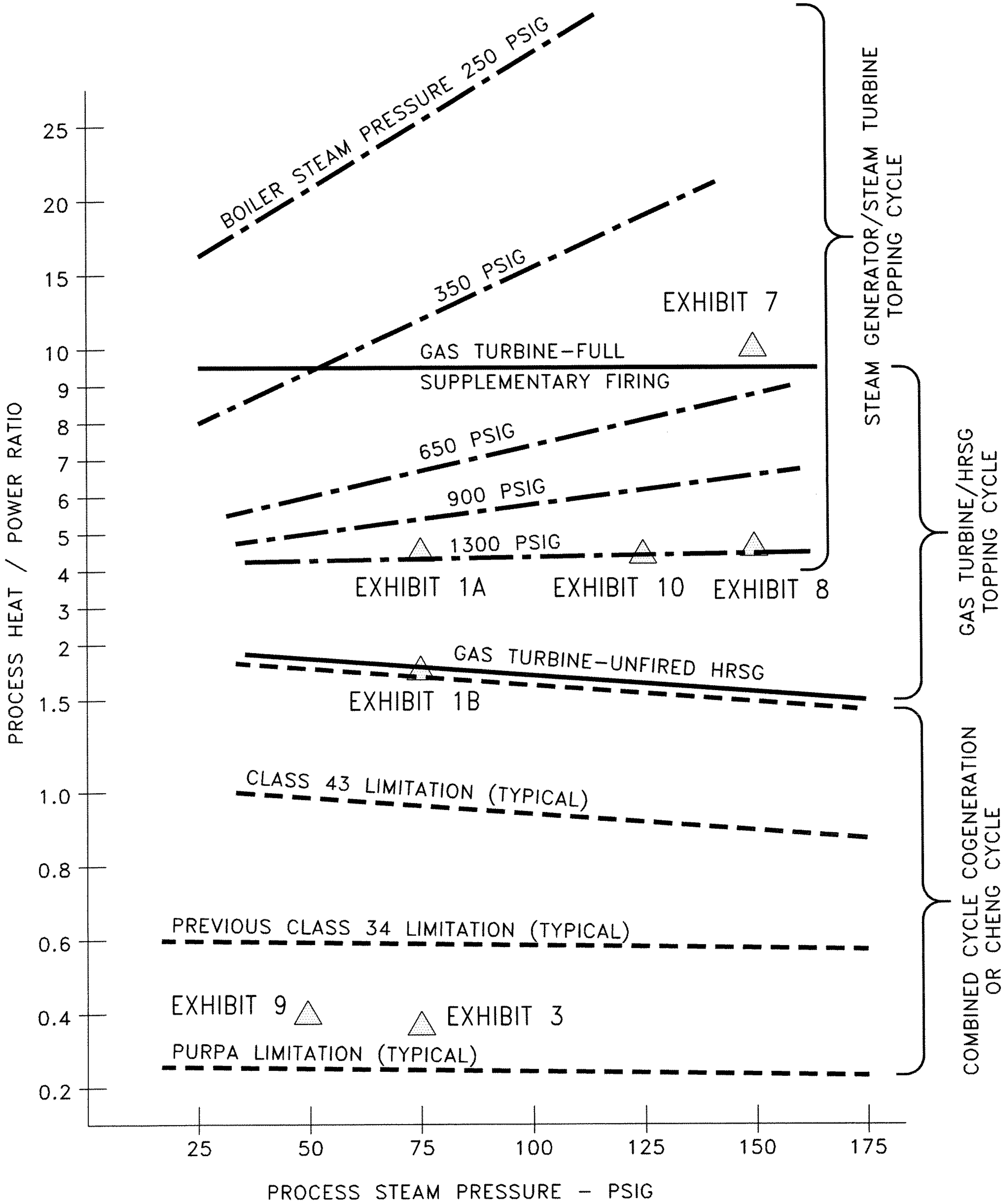
INTERNATIONAL ENGINEERING SERVICES INC.

COMBINED CYCLE COGENERATION

JAN. 2000	COGENERATION PRINCIPLES EXHIBIT 3



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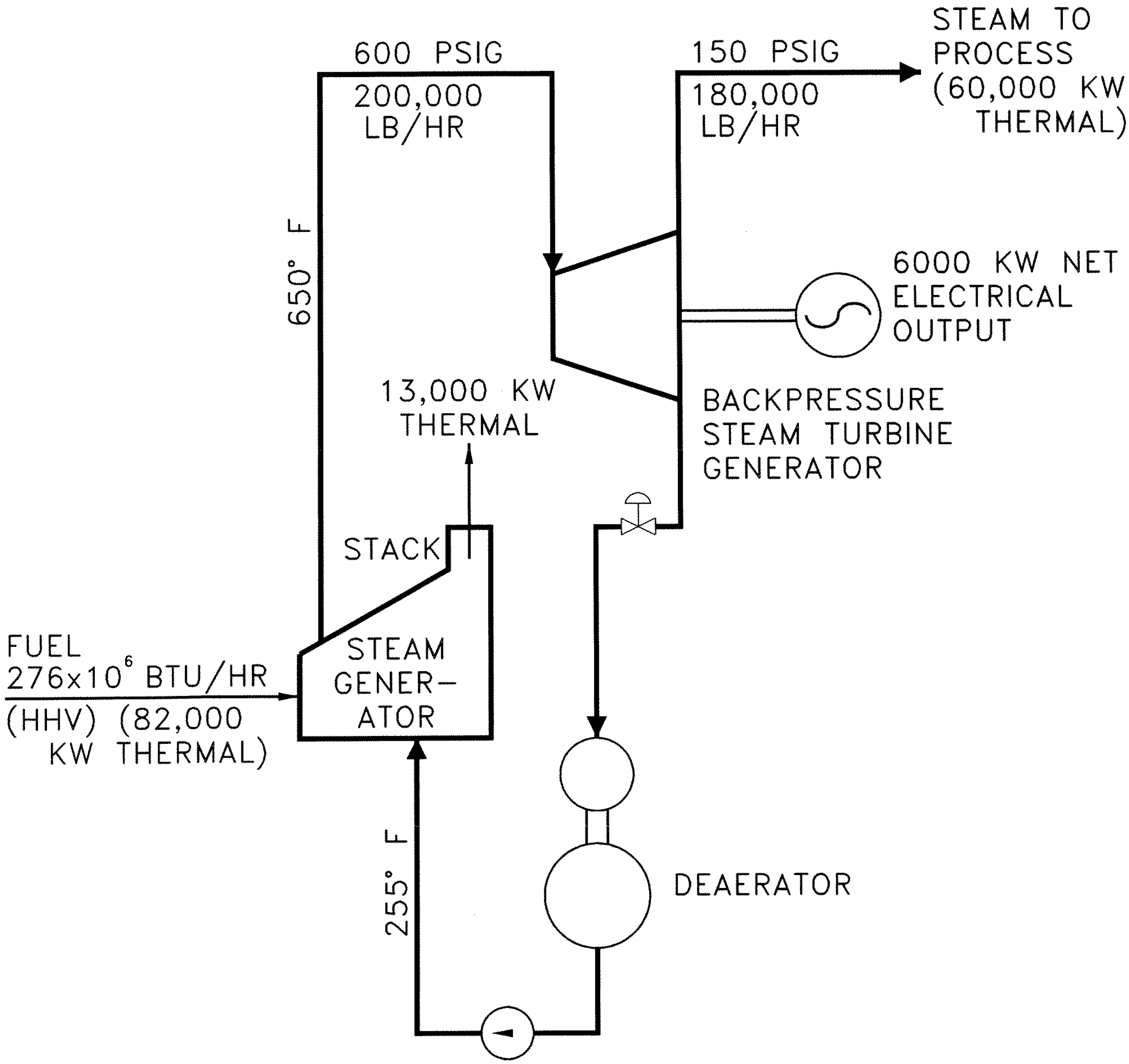
INTERNATIONAL ENGINEERING SERVICES INC.

HEAT TO POWER RATIOS

JAN. 2000	COGENERATION PRINCIPLES EXHIBIT 4

STEAM GENERATOR/BACKPRESSURE STEAM TURBINE



LOSSES AND AUXILIARY POWER = 3000 KW

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

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

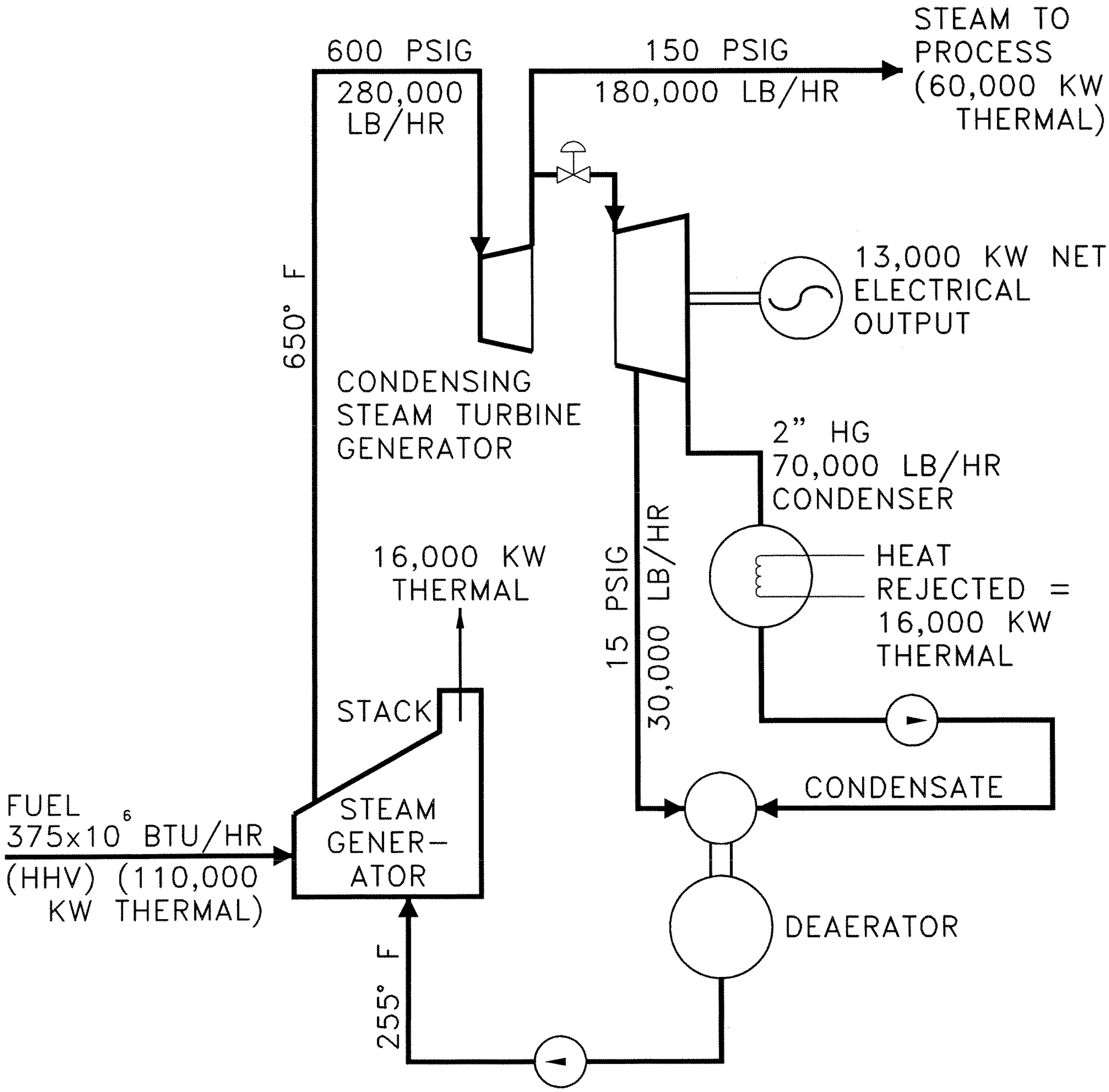
GRYPHON
INTERNATIONAL ENGINEERING SERVICES INC.

TYPICAL HEAT BALANCE
ALUMINA PLANT APPLICATION

JAN. 2000

COGENERATION PRINCIPLES
EXHIBIT 5

STEAM GENERATOR/CONDENSING STEAM TURBINE



LOSSES AND AUXILIARY POWER = 5000 KW

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

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

GRYPHON INTERNATIONAL ENGINEERING SERVICES INC.

TYPICAL HEAT BALANCE PULP & PAPER APPLICATION

JAN. 2000

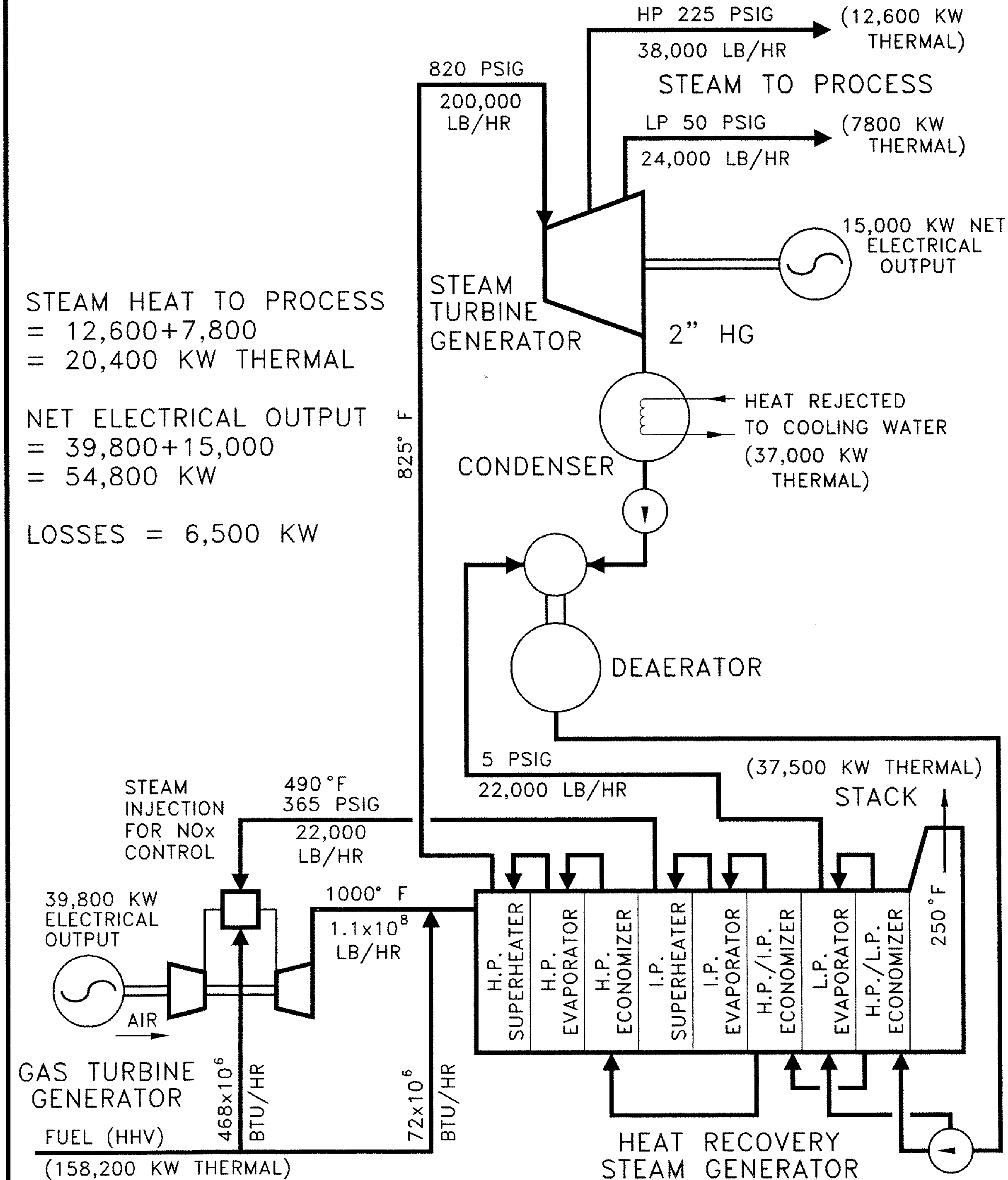
COGENERATION PRINCIPLES EXHIBIT 6

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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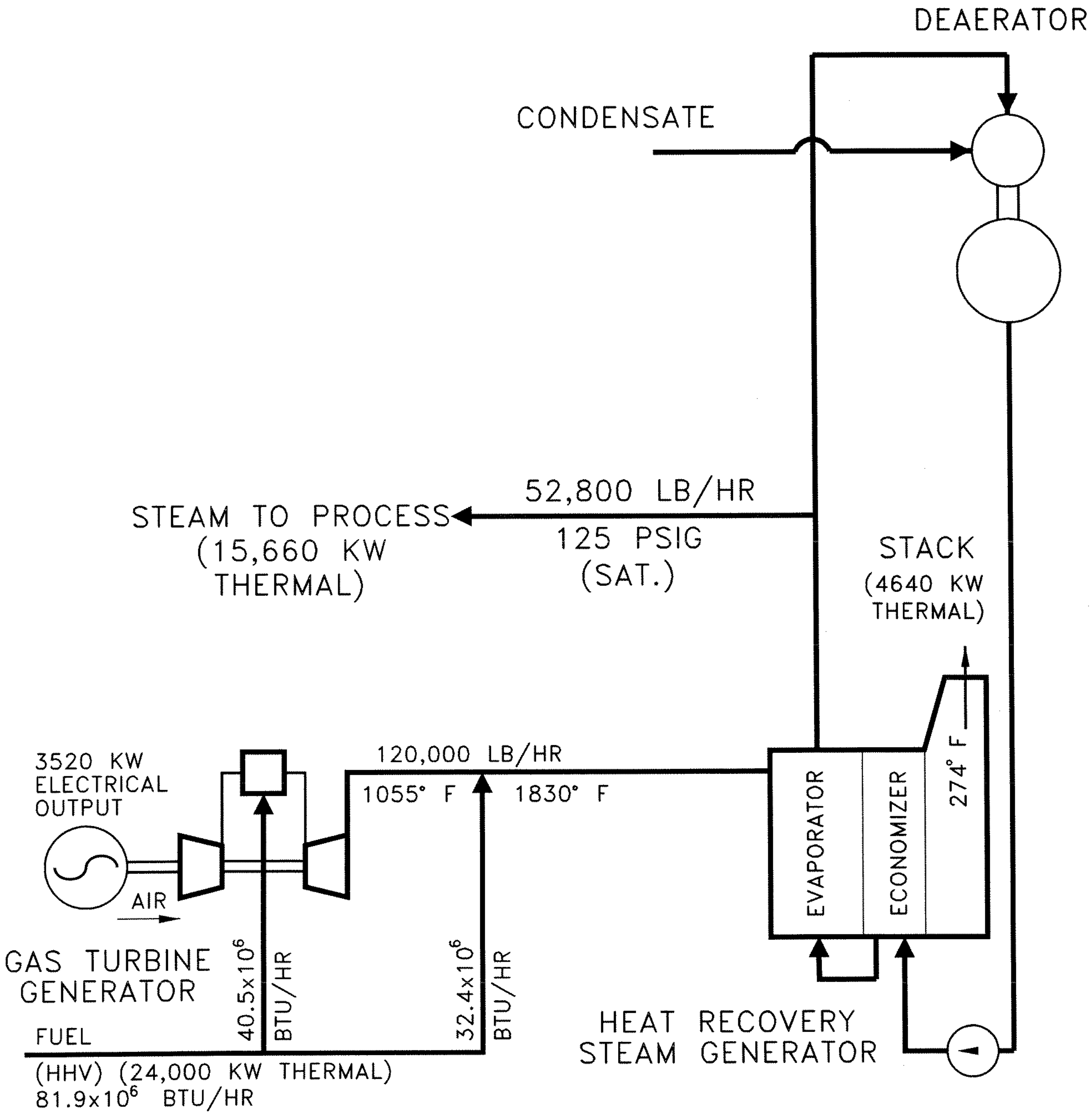
INTERNATIONAL ENGINEERING SERVICES INC.

TYPICAL HEAT BALANCE
COMBINED CYCLE APPLICATION

JAN. 2000	COGENERATION PRINCIPLES EXHIBIT 7

GAS TURBINE GENERATOR/HEAT RECOVERY STEAM GENERATOR



LOSSES AND AUXILIARY POWER = 600 KW

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

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

GRYPHON INTERNATIONAL ENGINEERING SERVICES INC.	
TYPICAL HEAT BALANCE SMALL PROCESS PLANT APPLICATION	
JAN. 2000	COGENERATION PRINCIPLES EXHIBIT 8