



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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CEM Engineering

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

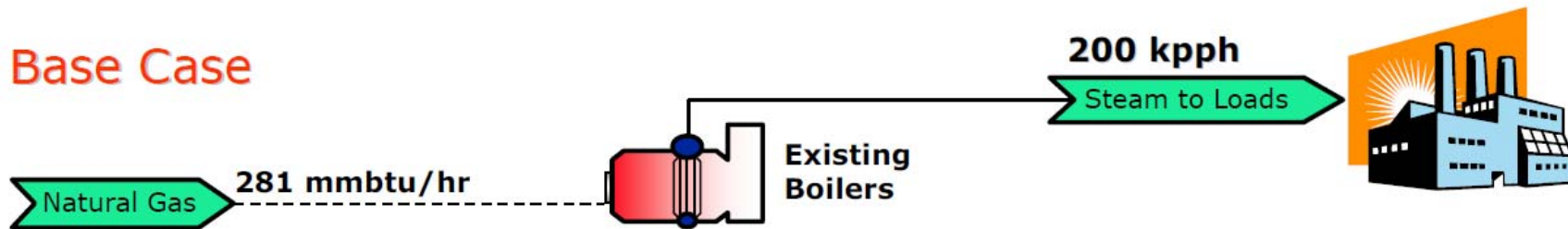
Presented at the Gas Turbines Energy Network (GTEN) 2019 Symposium
Banff, Alberta, Canada - October 2019

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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).”

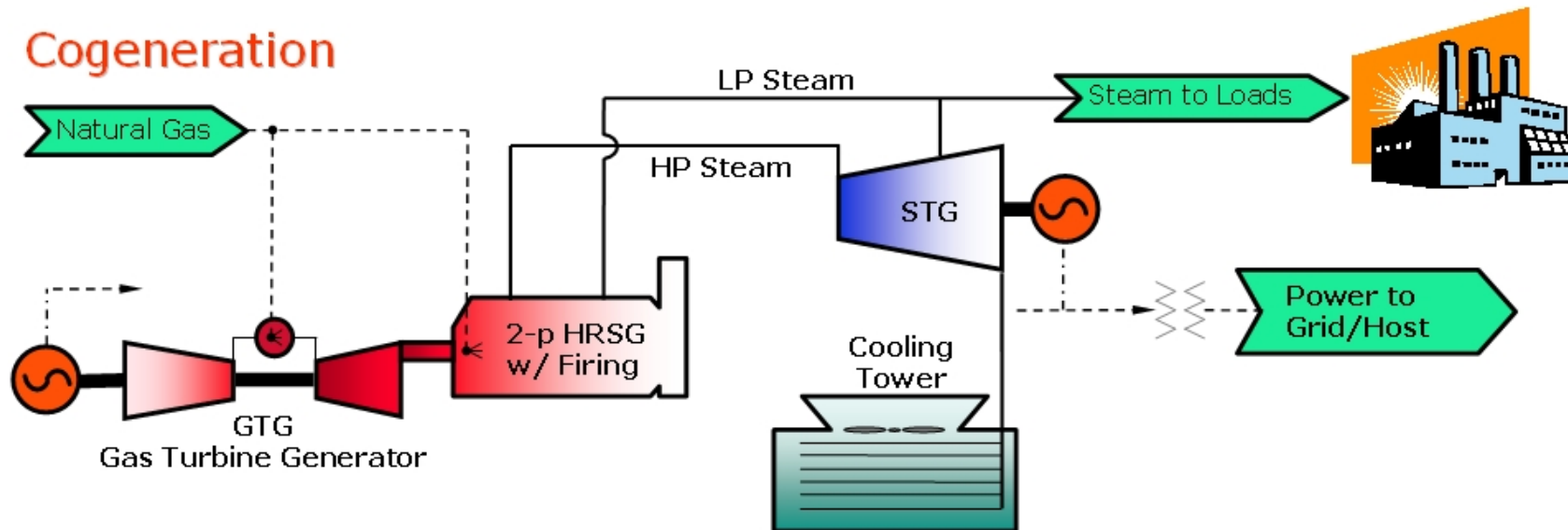
Base Case



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”

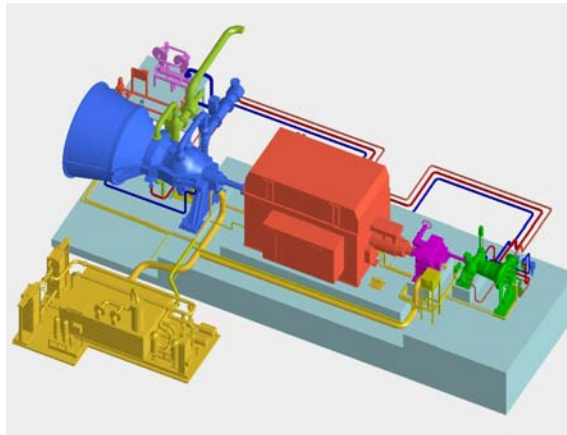
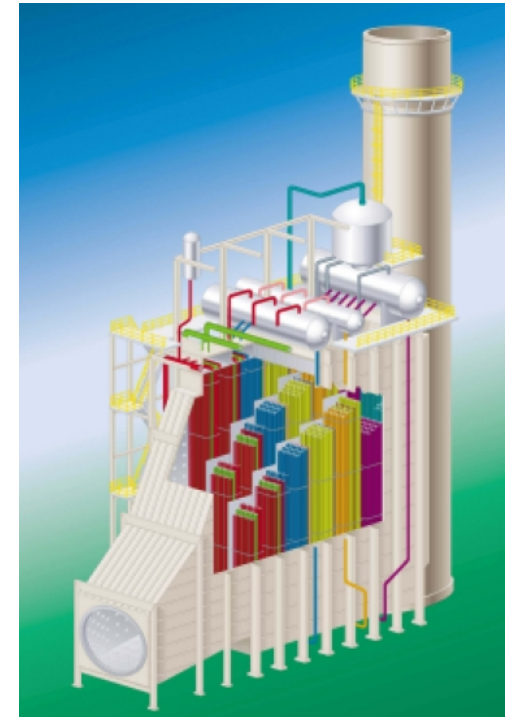
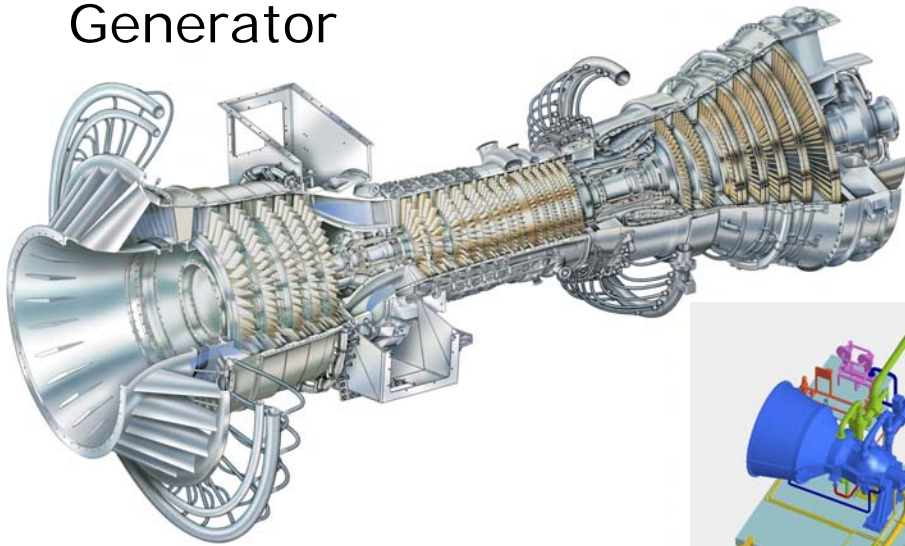
Cogeneration



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 reheated 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.

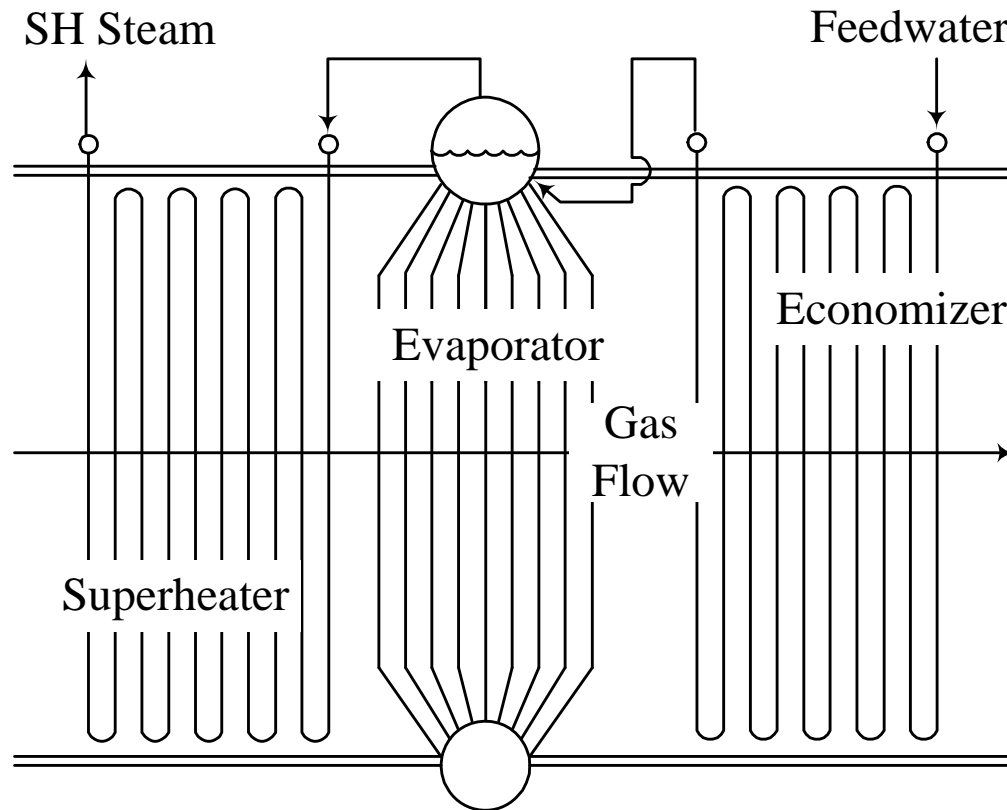


Typical HRSG Configuration (Drum-Type)

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.

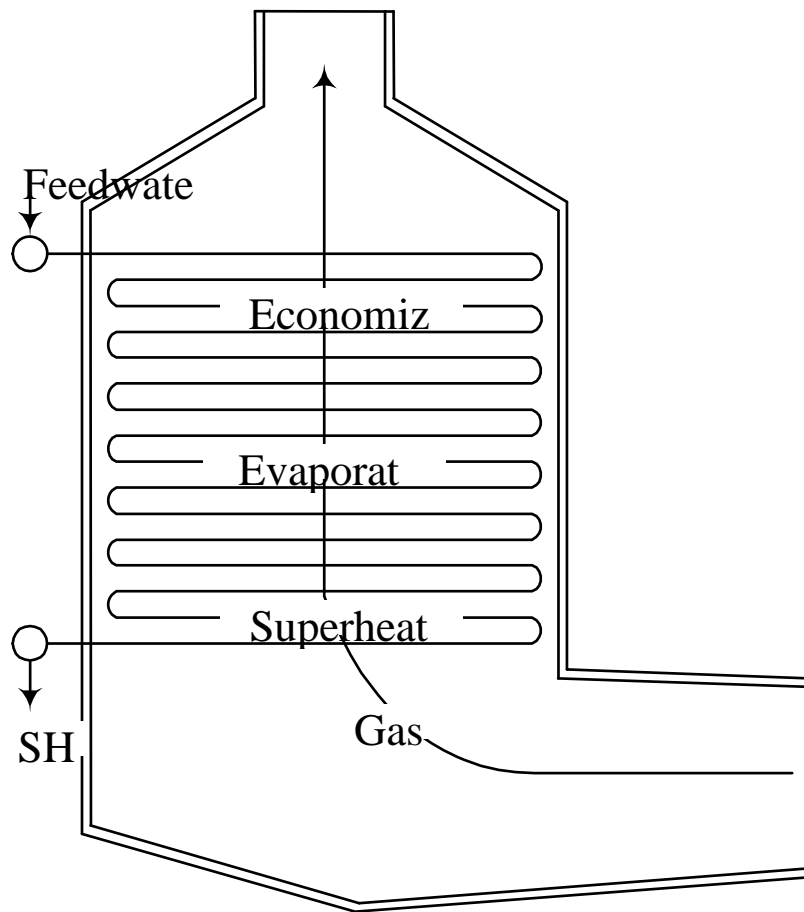
The feedwater/steam flows in reverse to the turbine exhaust gases.



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.

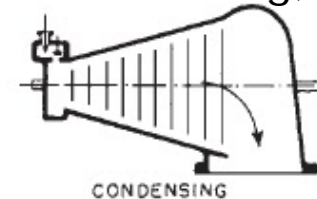
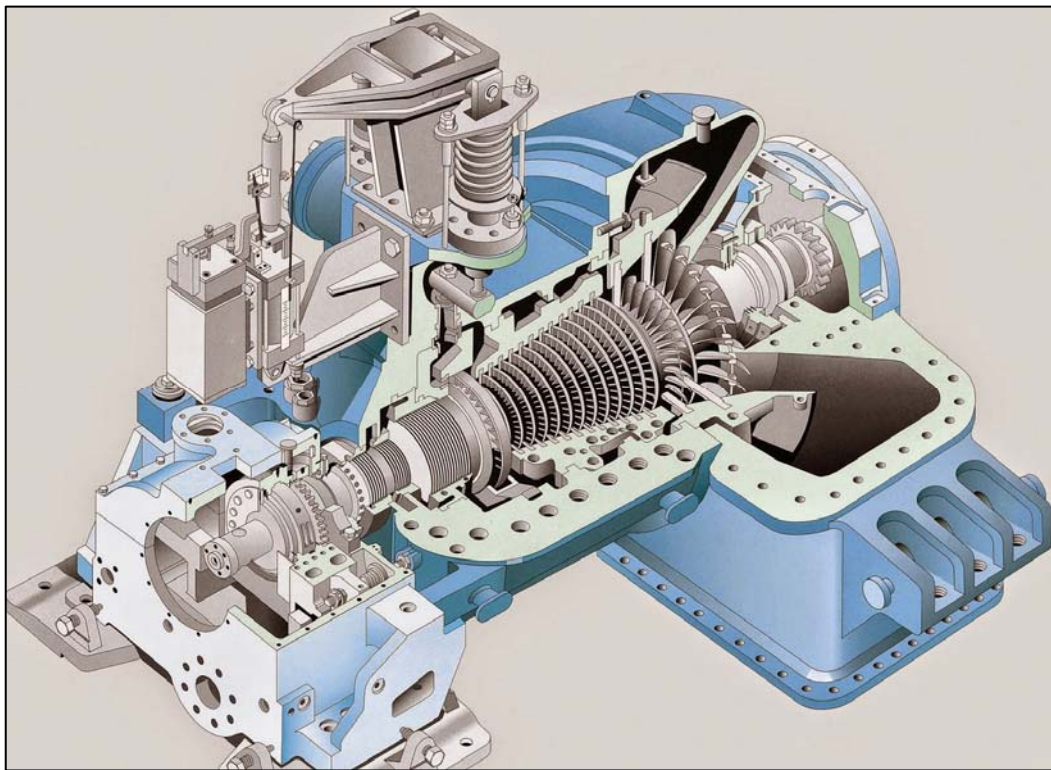
An OTSG variation producing wet saturated steam is used for Enhanced Oil Recovery (EOR) in the Albertan Oil Sands regions.



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.



CONDENSING



BACK - PRESSURE



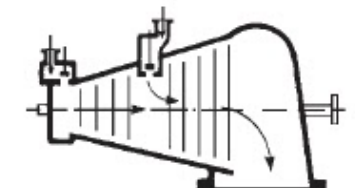
AUTOMATIC SINGLE-EXTRACTION



UNCONTROLLED - EXTRACTION



SINGLE - REHEAT

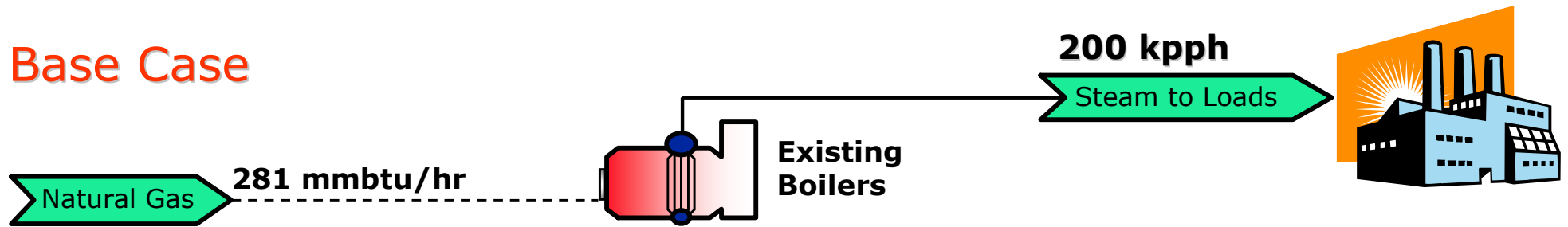


MIXED - PRESSURE



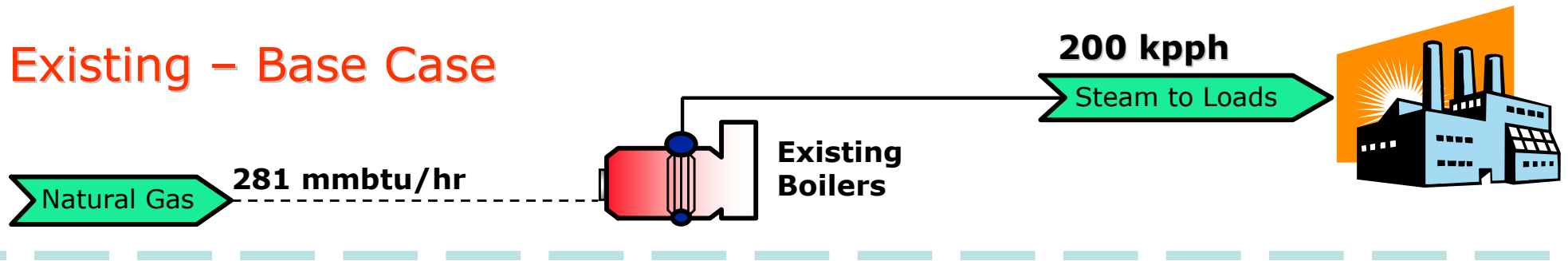
COGENERATION EXAMPLE

Base Case



COGENERATION EXAMPLE

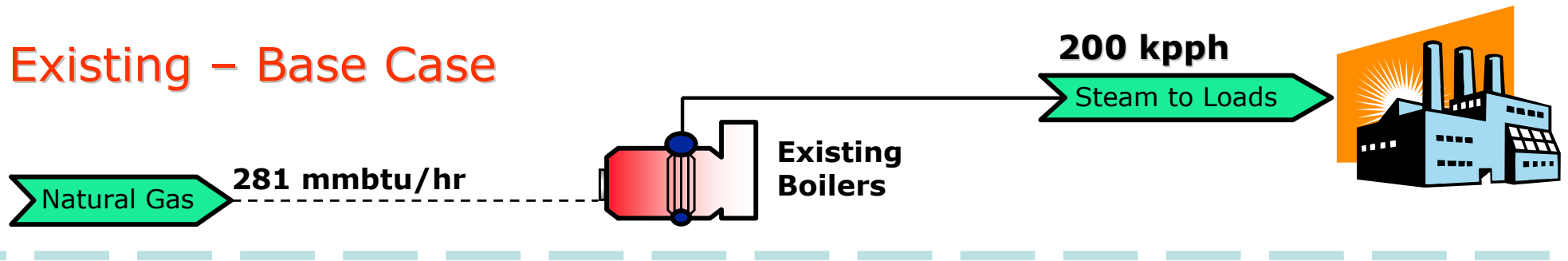
Existing – Base Case



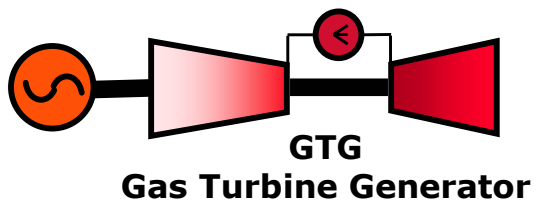
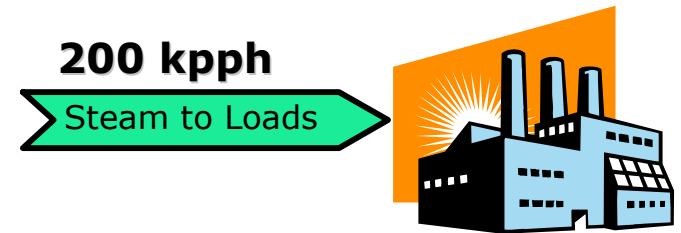
Cogeneration Case

COGENERATION EXAMPLE

Existing – Base Case

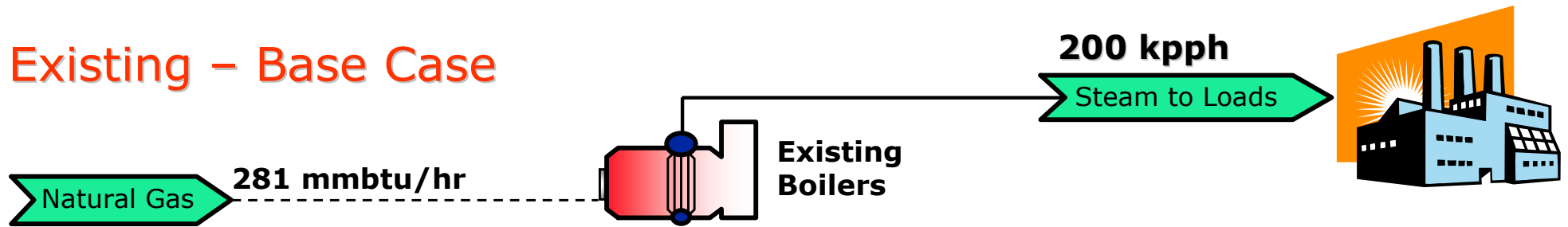


Cogeneration Case

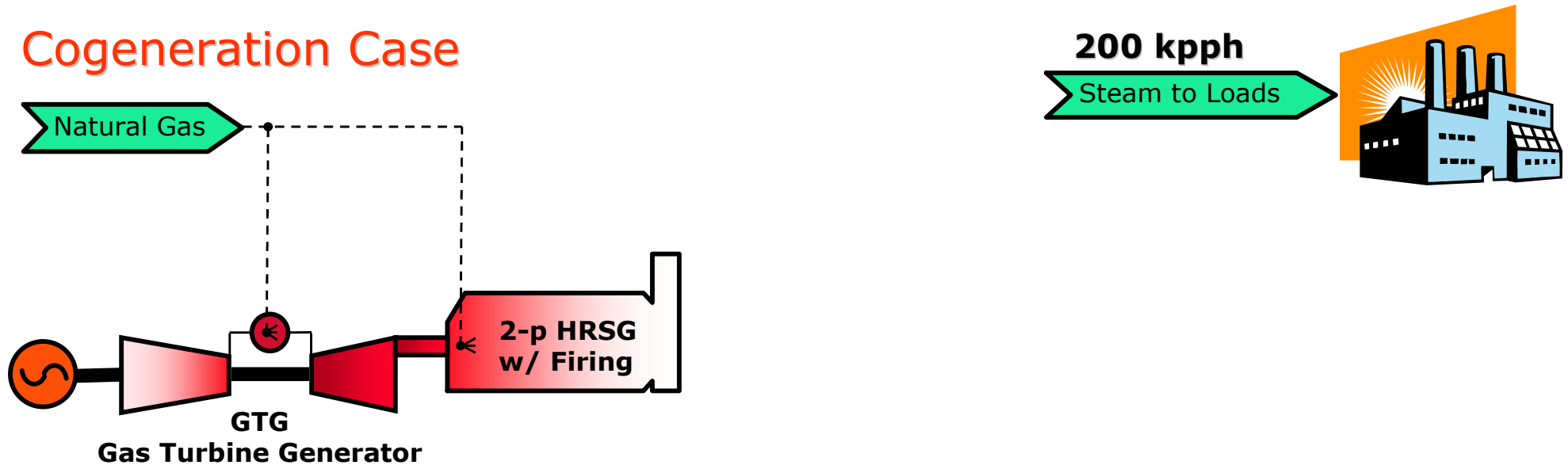


COGENERATION EXAMPLE

Existing – Base Case

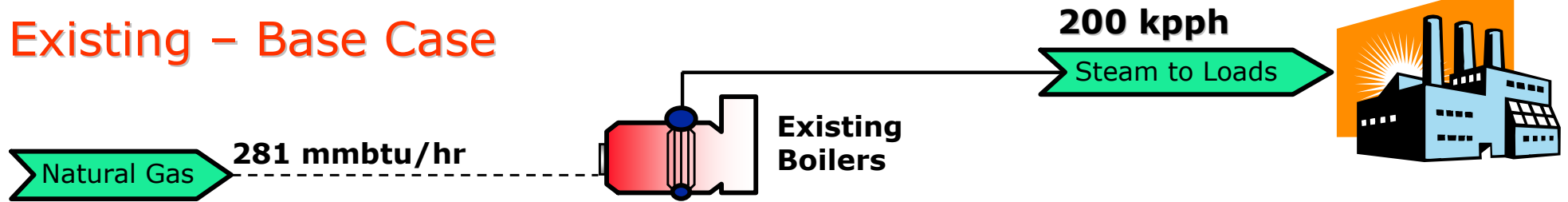


Cogeneration Case

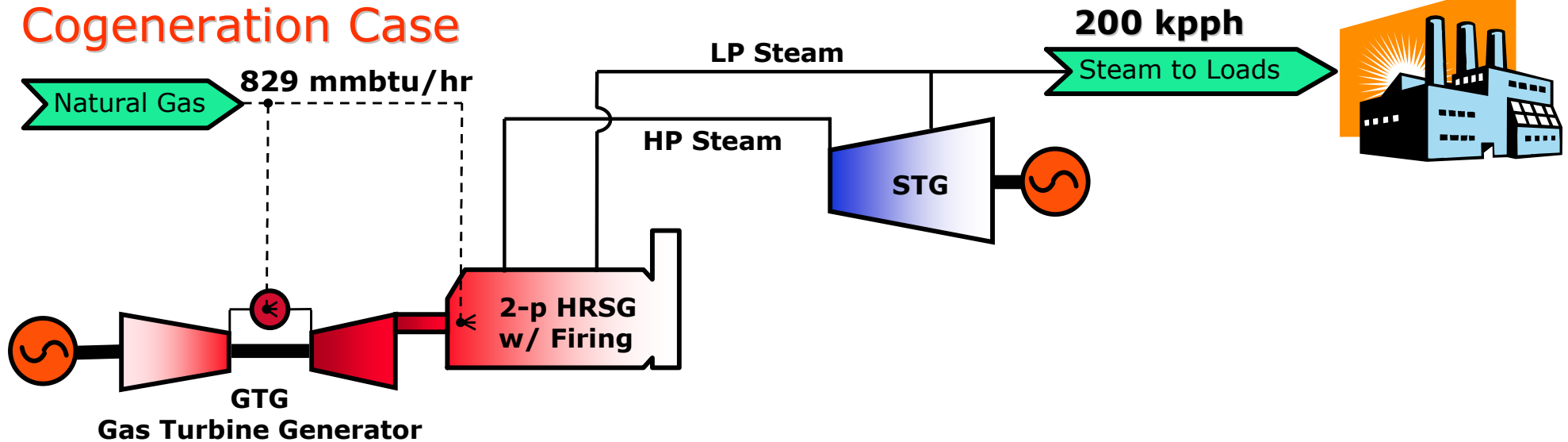


COGENERATION EXAMPLE

Existing – Base Case

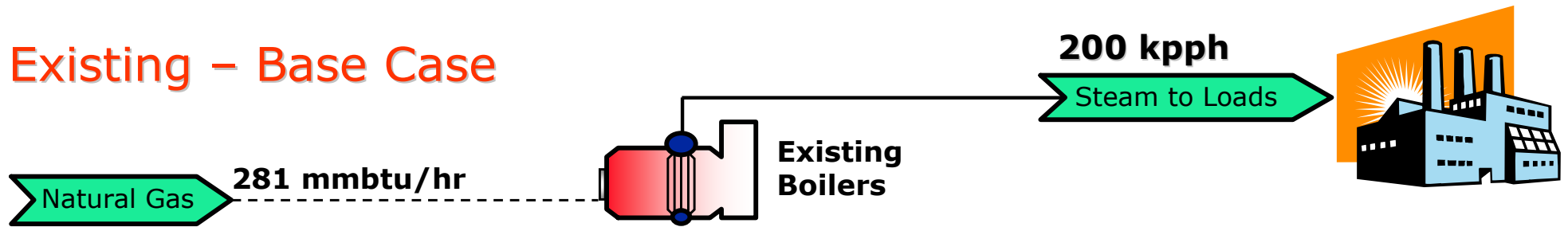


Cogeneration Case

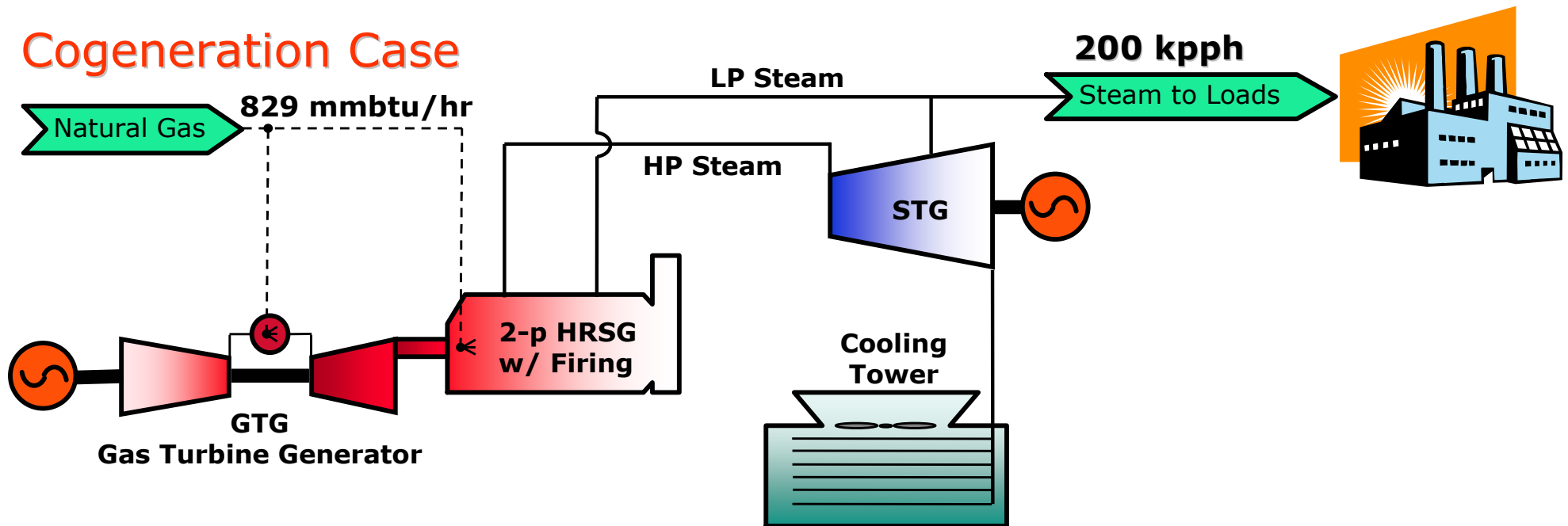


COGENERATION EXAMPLE

Existing – Base Case

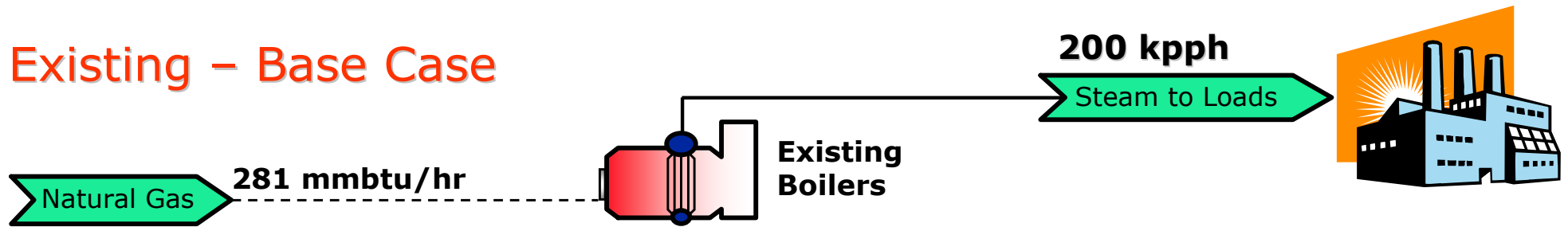


Cogeneration Case

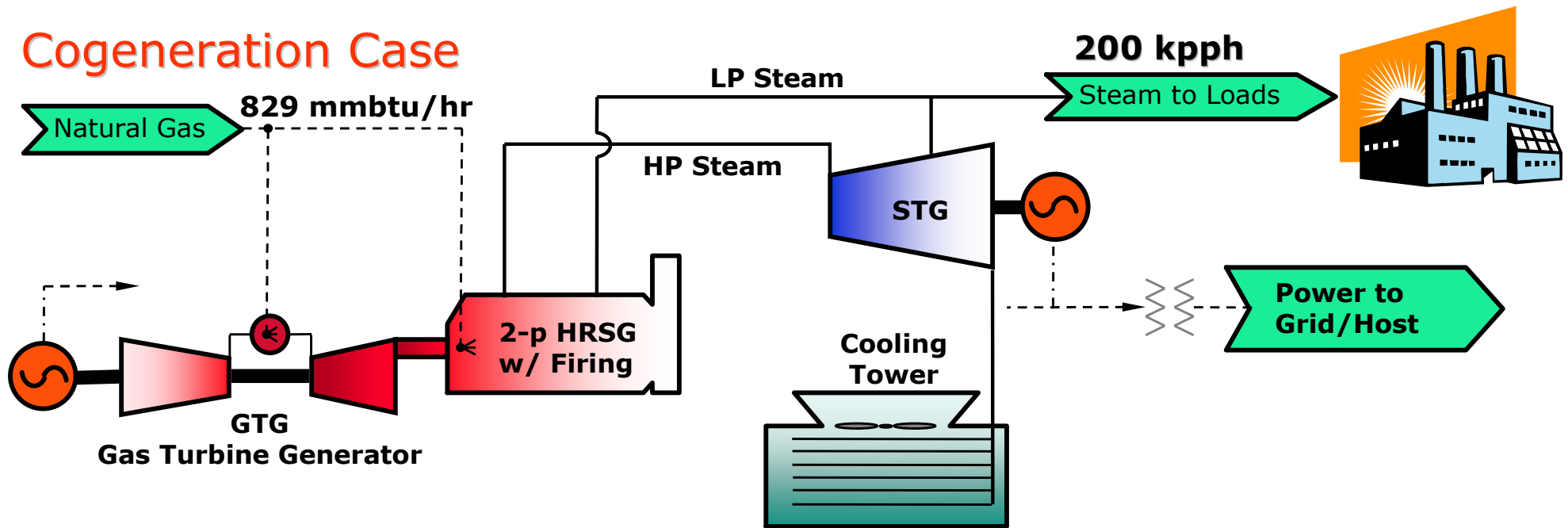


COGENERATION EXAMPLE

Existing – Base Case

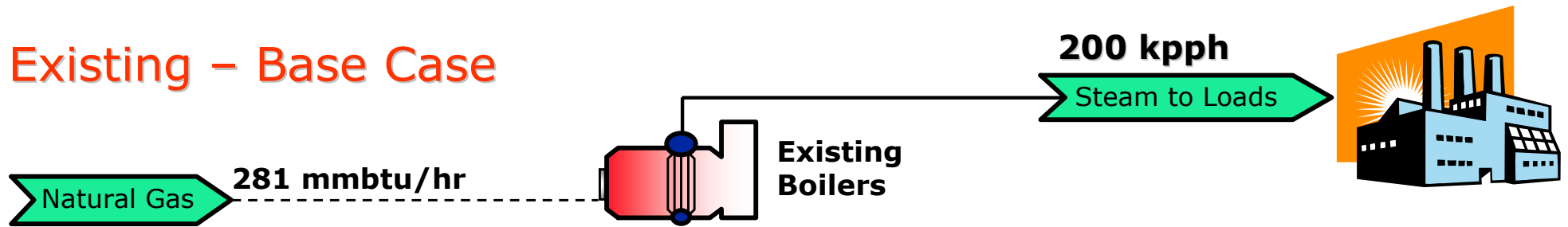


Cogeneration Case

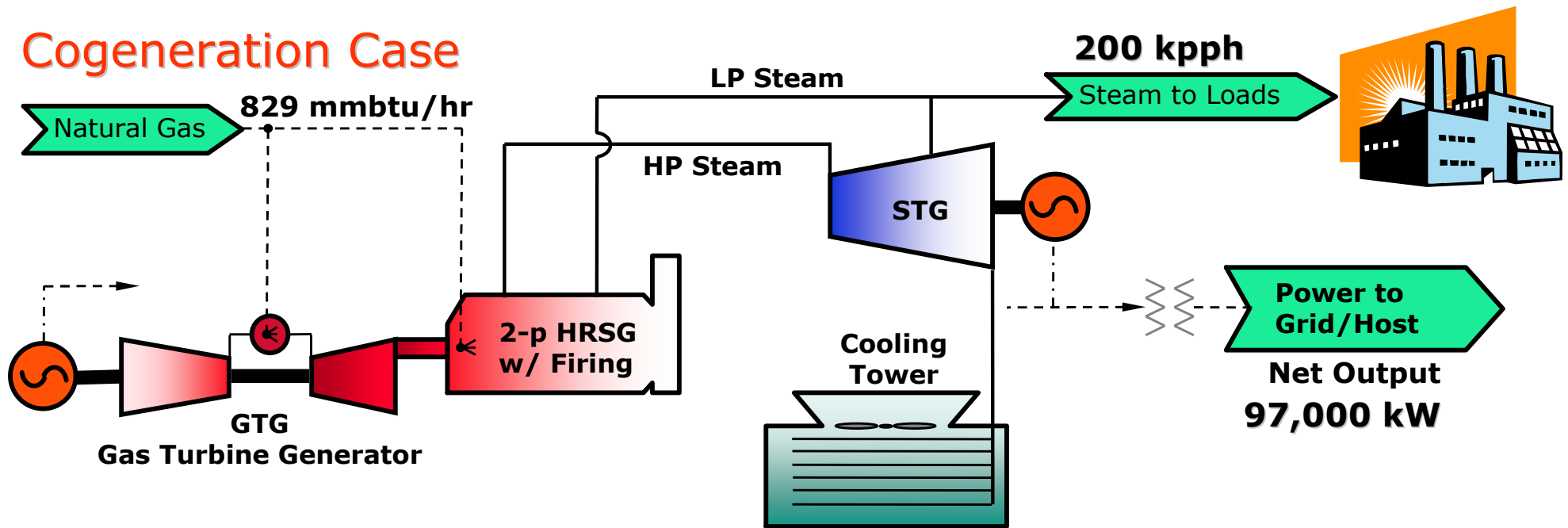


COGENERATION EXAMPLE

Existing – Base Case

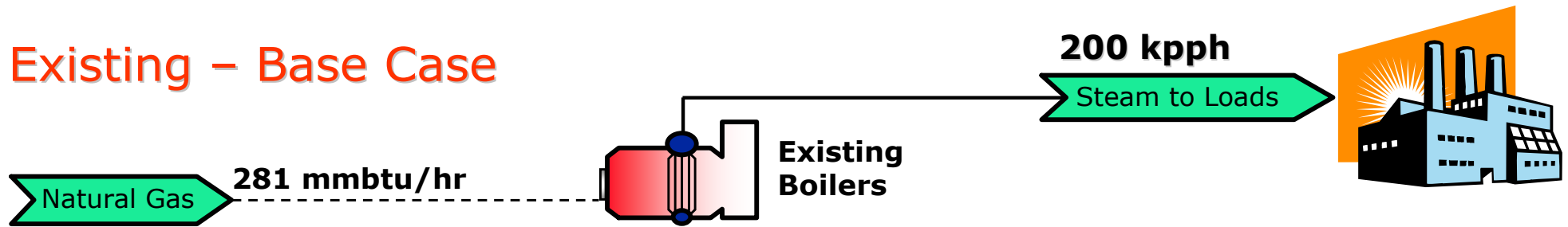


Cogeneration Case

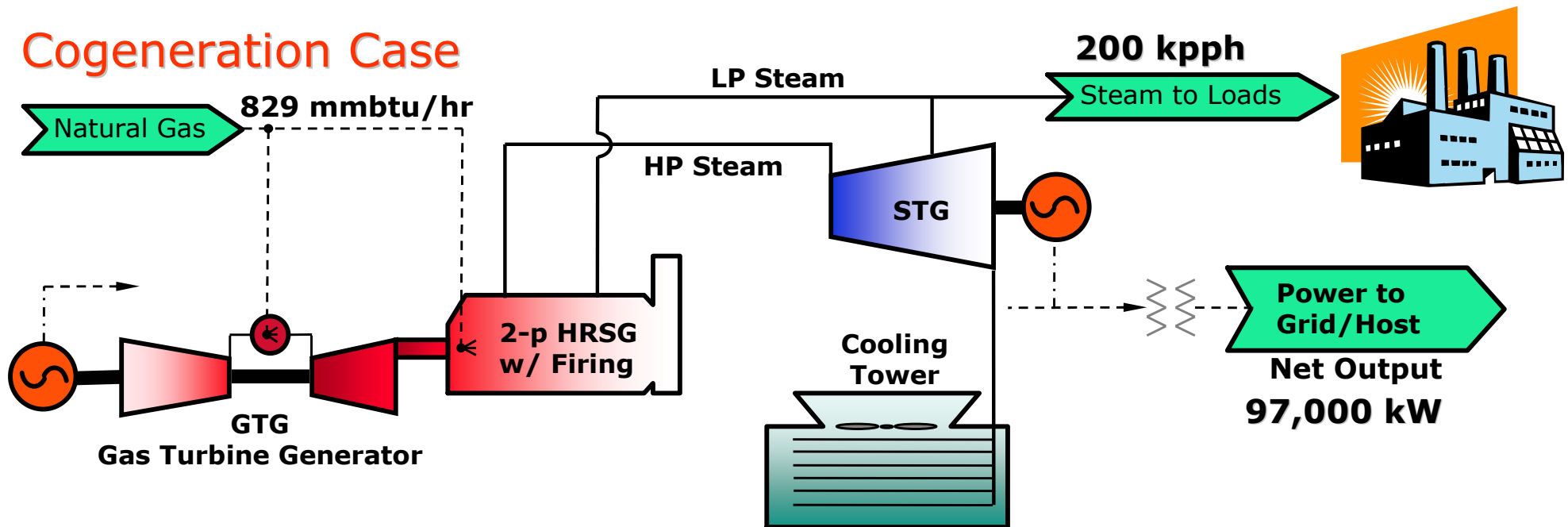


COGENERATION EXAMPLE

Existing – Base Case



Cogeneration Case



Cycle Inputs:

Fuel: 829 mmbtu/hr

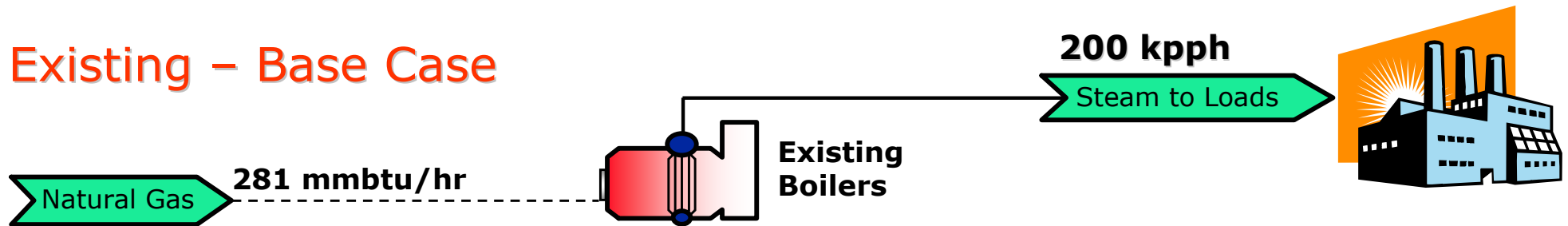
Cycle Outputs:

Steam: 200 kpph

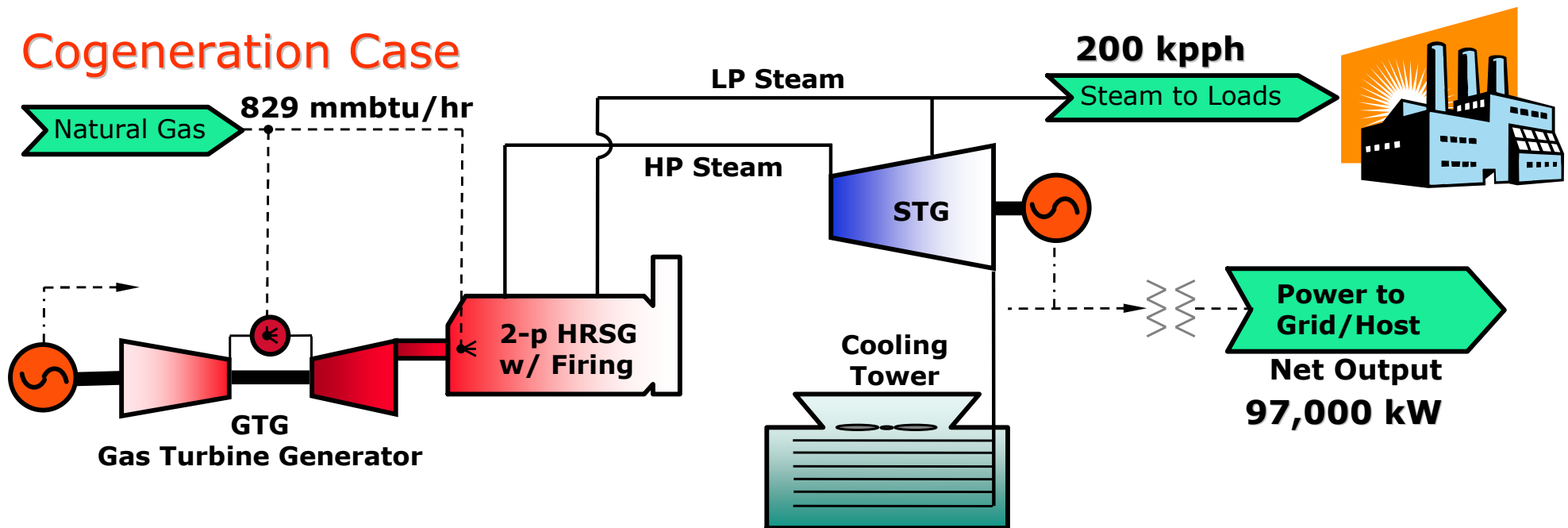
Power: 97,000 kW

COGENERATION EXAMPLE

Existing – Base Case



Cogeneration Case



Cycle Inputs:

Fuel: 829 mmbtu/hr

Cycle Outputs:

Steam: 200 kpph
Power: 97,000 kW

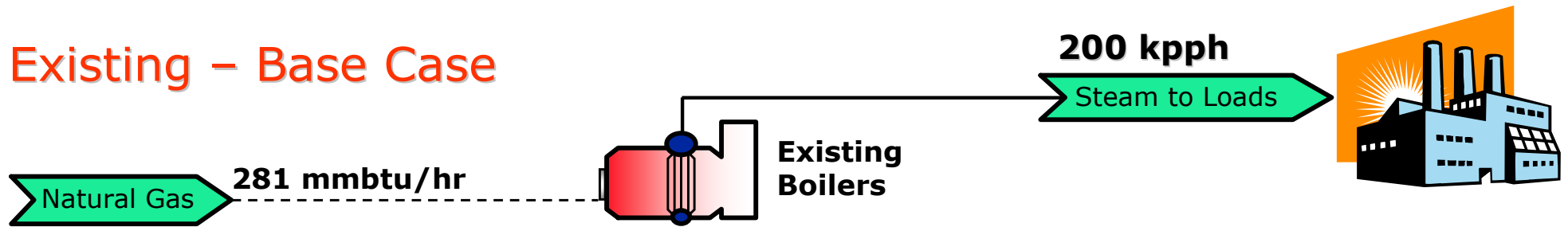
Cogeneration or CHP Efficiency

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

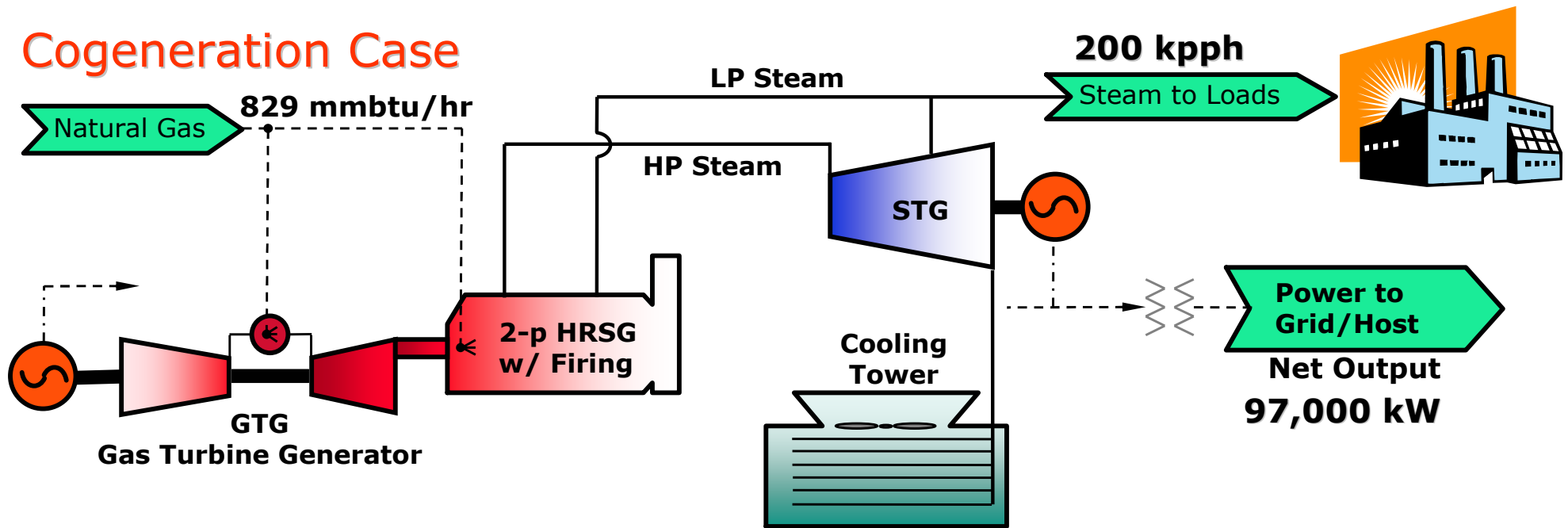
= **64%** (or a Heat Rate of **5328** btu/kW.hr)

COGENERATION EXAMPLE

Existing – Base Case



Cogeneration Case

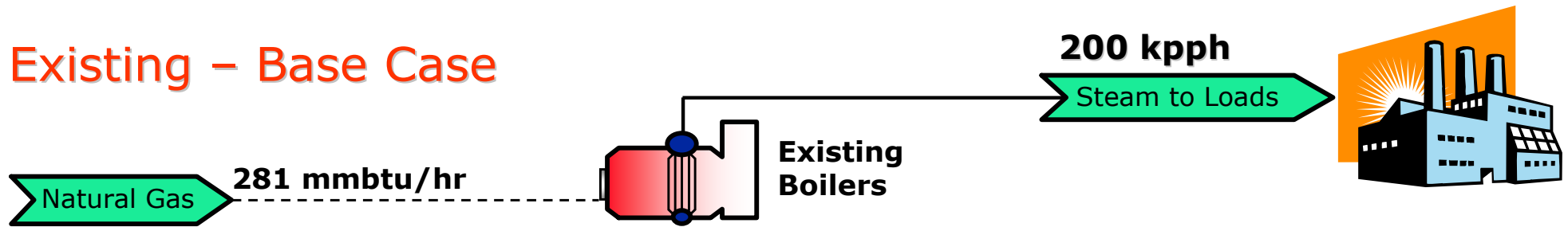


Total Cogeneration Fuel

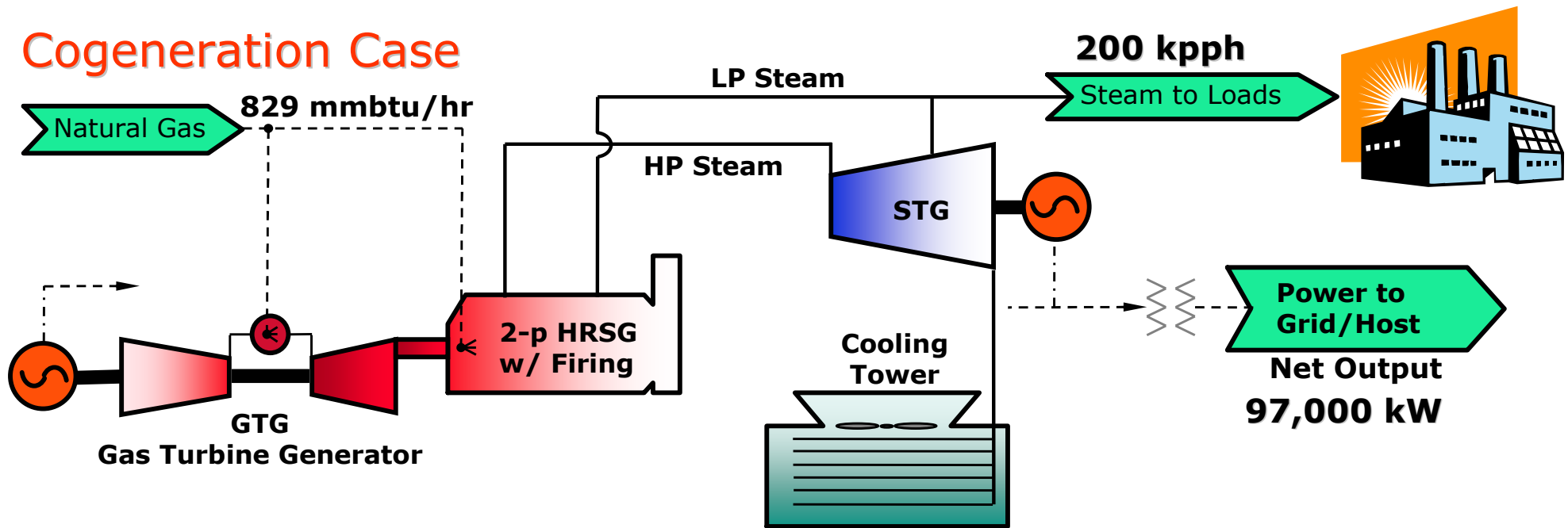
829 mmbtu/hr

COGENERATION EXAMPLE

Existing – Base Case



Cogeneration Case

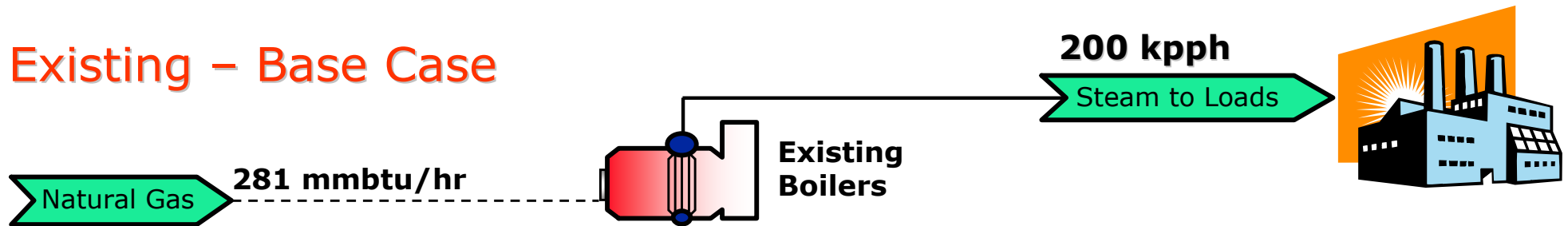


Total Cogeneration Fuel
Fuel-Chargeable-to-Steam (FCS)

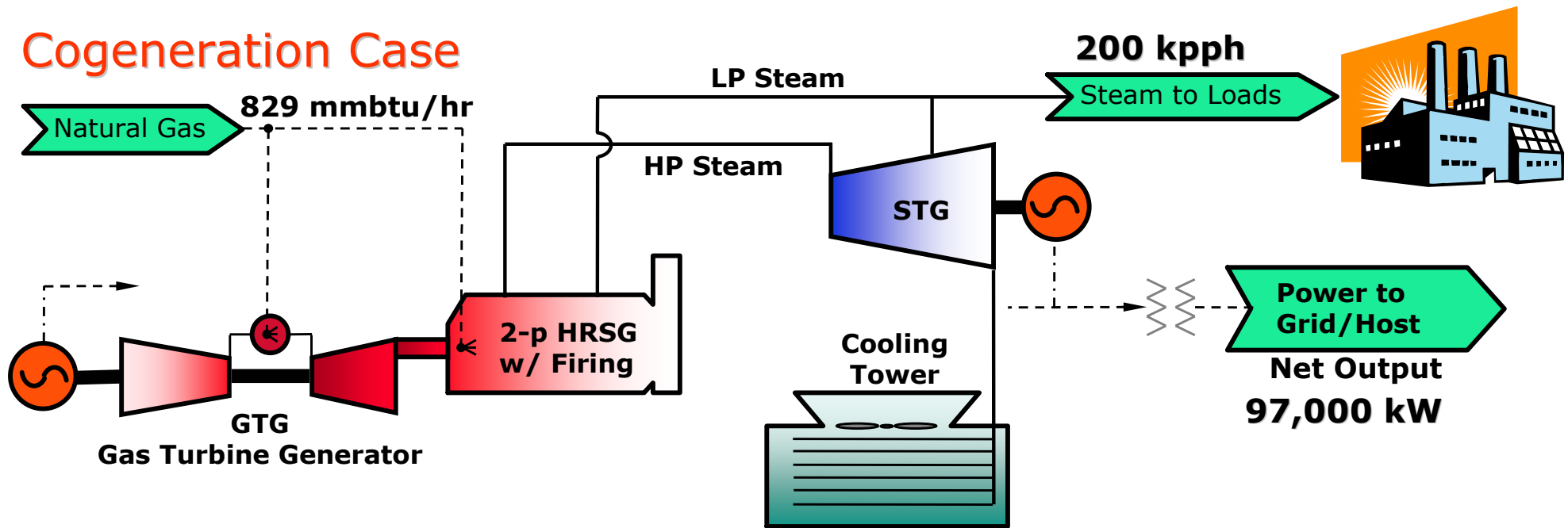
829 mmbtu/hr
281 mmbtu/hr

COGENERATION EXAMPLE

Existing – Base Case



Cogeneration Case

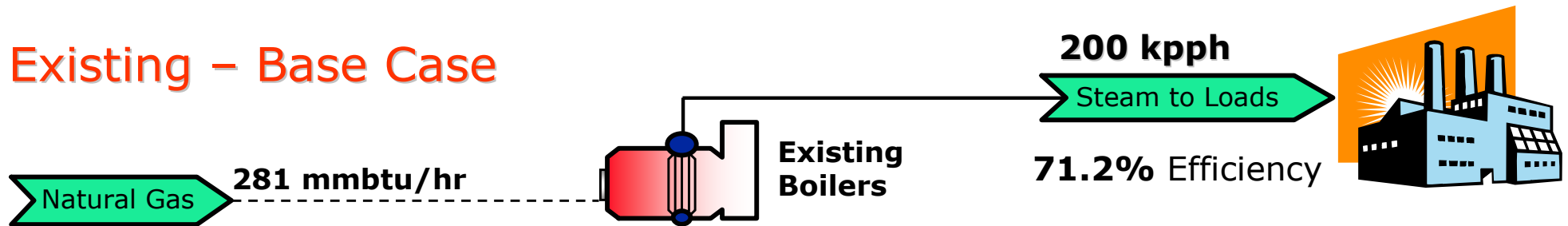


Total Cogeneration Fuel
Fuel-Chargeable-to-Steam (FCS)
Fuel-Chargeable-to-Power (FCP)

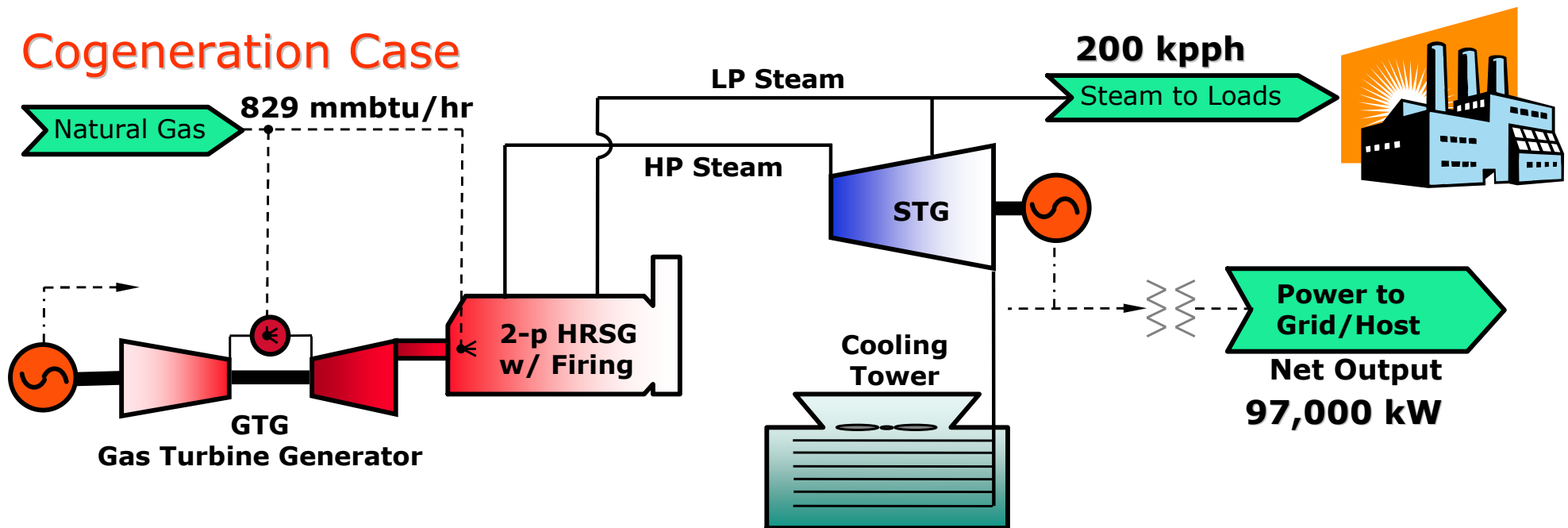
829 mmbtu/hr
-281 mmbtu/hr
548 mmbtu/hr

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



COGENERATION, COMBINED-CYCLE & POWER PLANT BASICS®



Portlands Energy Centre – Toronto



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ModernPowerSystems

DUNKIRK 2x400 MWe COMBINED CYCLE POWER PLANT

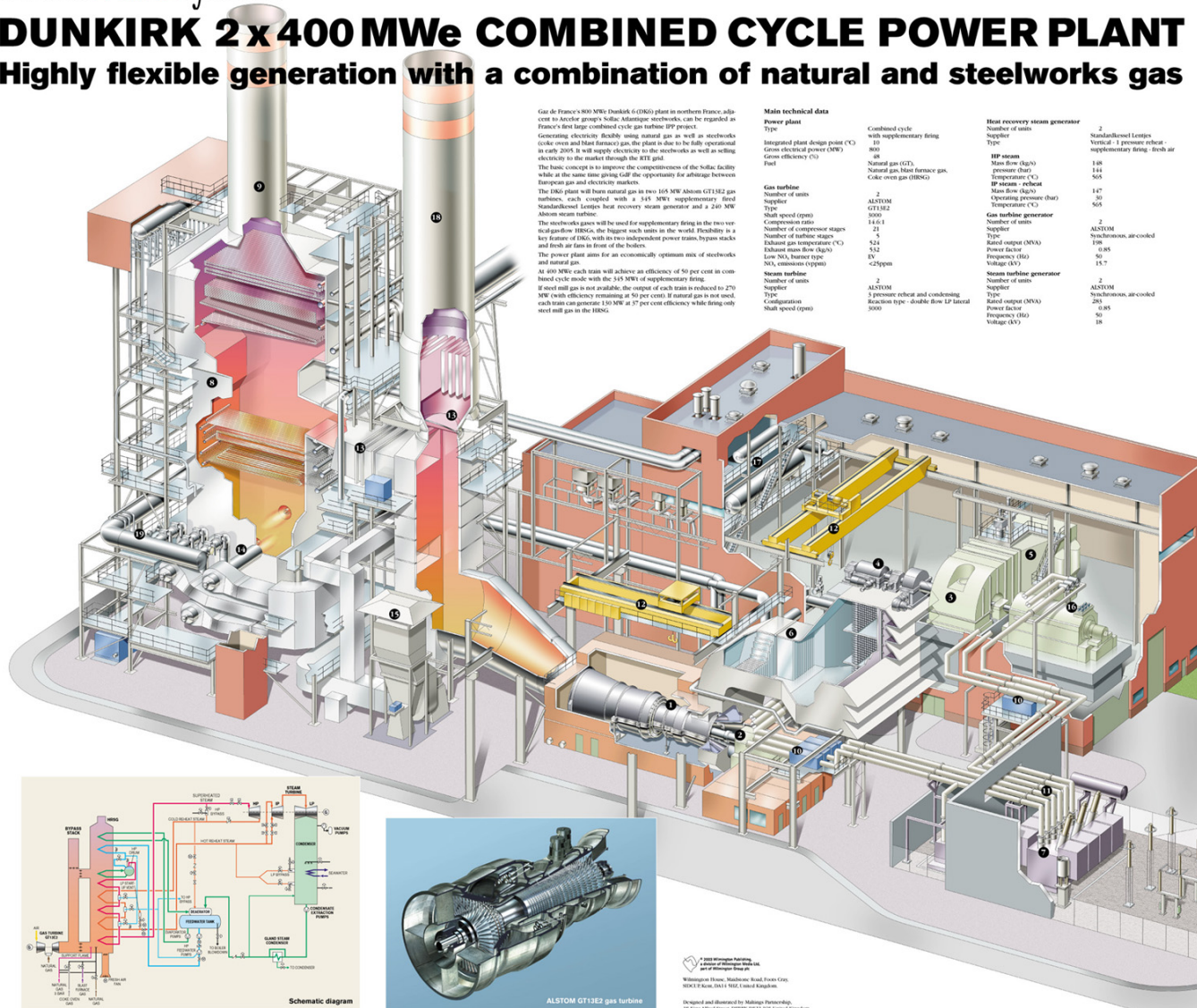
Highly flexible generation with a combination of natural and steelworks gas

ALSTOM

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Gas de France's 800 MW Dunkirk 6 (DK6) plant in northern France, adjacent to another group's Val de Marais steelworks, can be regarded as France's first large combined cycle gas turbine (CCGT) 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 steel facility while at the same time giving GDF the opportunity for arbitrage between European gas and electricity markets.

The DK6 plant will have natural gas in two 145 MW Alstom GT1302 gas turbines, each coupled with a 345 MW supplementary fired Standardised Lignite heat recovery steam generator and a 240 MW Alstom steam turbine.

The steelworks gases will be used for supplementary firing in the two vertical-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 MW 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 140 MWe at 57 per cent efficiency while firing only steel mill gas in the HRSG.

Main technical data

Power plant

Type
Integrated plant design point (C)
Gross electrical power (MW)
Gross efficiency (%)

800
50
56

Natural gas (GTL)
Natural gas, blast furnace gas,
Coke-oven gas (HBG)

2
2

Gas turbine

Number of units
Supplier

2
ALSTOM

Type
GT1302

3000

Compressor ratio
14.6:1

Number of compressor stages
21

Exhaust gas temperature (°C)
524

Exhaust gas flow (kg/s)
532

Low NO_x burner type
DX

NO_x emission (ppm)
≤25ppm

Steam turbine

Number of units
Supplier

2
ALSTOM

Type
3 pressure reheat and condensing

Reaction type - double flow LP axial

3000

Heat recovery steam generator

Number of units
Supplier

2
Standardised Lignite

Vertical - 1 pressure reheat -
supplementary firing - fresh air

140

Main flow (kg/s)
pressure (bar)

144

Temperature (°C)
144

IP steam - reheat
Main flow (kg/s)
Operating pressure (bar)

147

Temperature (°C)
30

Gas turbine generator

Number of units
Supplier

2
ALSTOM

Type
Synchronous, air-cooled

108

Rated output (MVA)
0.85

Power factor
50

Frequency (Hz)
15.7

Steam turbine generator

Number of units
Supplier

2
ALSTOM

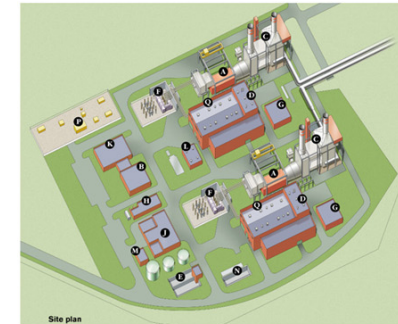
Type
Synchronous, air-cooled

285

Rated output (MVA)
0.85

Power factor
50

Frequency (Hz)
18



Key - site plan

A. Gas turbine

B. Control building

C. Heat recovery steam generator

D. Freshwater tank

E. Recirculation pump building

F. Industrial water recovery pit

G. Transformer

H. Unit electrical building

I. Emergency diesel generator

J. Common electrical building

K. Water treatment plant

L. Workshop & warehouse

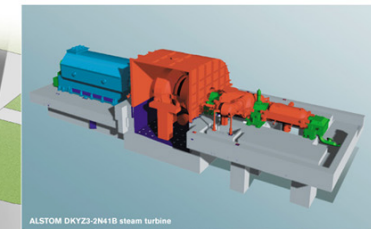
M. Air compressor station

N. Fire fighting pump house

O. Steam water basin

P. Natural gas expansion station (GDF)

Q. Steam turbine building



ALSTOM DK723-3M41B steam turbine

Key

1. GT1302 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. Run duct

12. Overhead crane

13. HRSG diverter dampers

14. HRSG burners

15. Fresh air fan

16. GT electrical generator - TEWAC

17. Freshwater tank

18. Bypass stack

19. Blast furnace gas pipe

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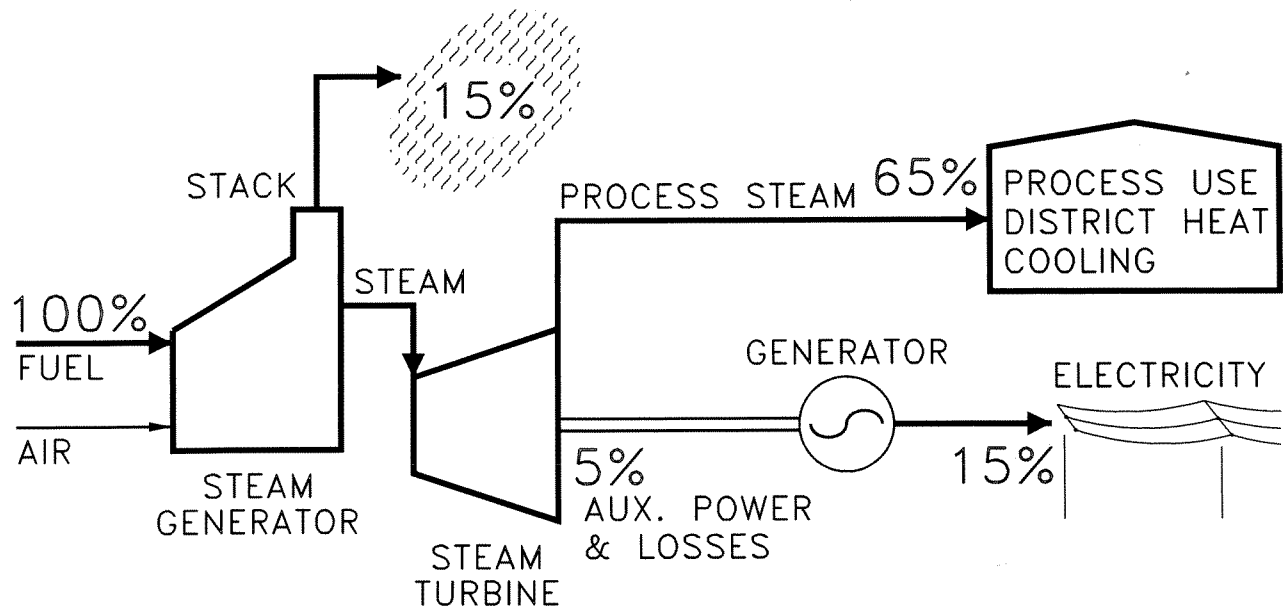


FUEL → ELECTRICITY → PROCESS HEAT

A. STEAM GENERATOR/STEAM TURBINE

$$\text{THERMAL EFFICIENCY} = 65 + 15 = 80\%$$

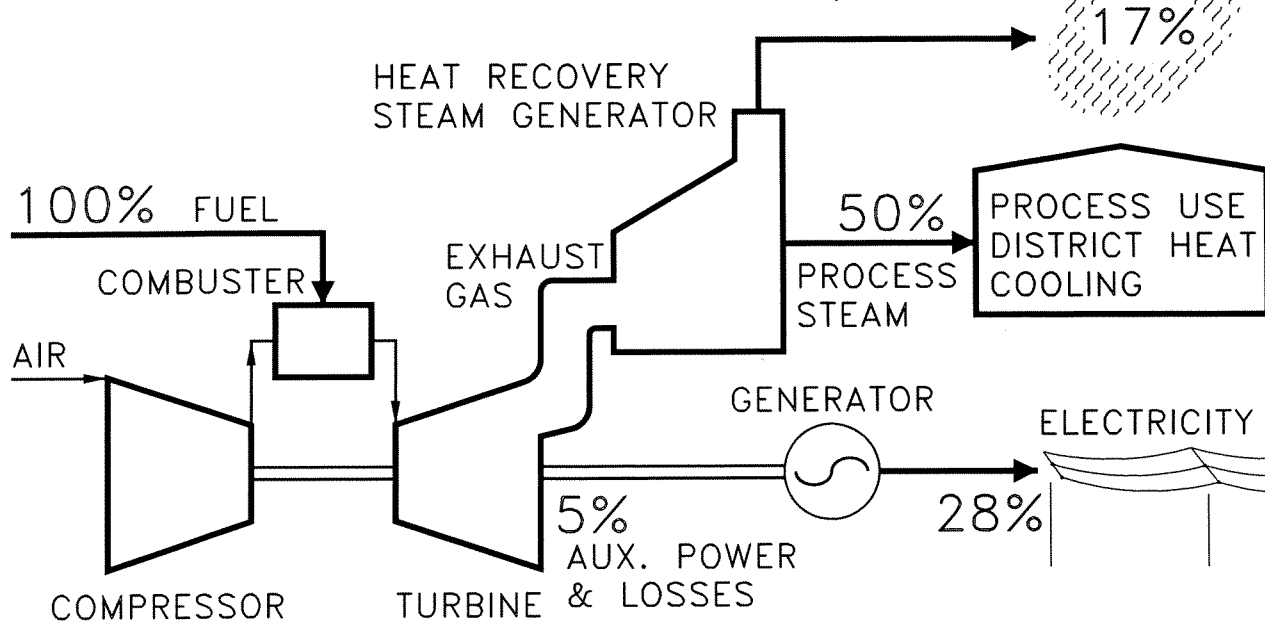
$$\text{HEAT TO POWER RATIO} = 65/15 = 4.3$$



B. GAS TURBINE/HRSG

$$\text{THERMAL EFFICIENCY} = 50 + 28 = 78\%$$

$$\text{HEAT TO POWER RATIO} = 50/28 = 1.8$$



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INTERNATIONAL ENGINEERING SERVICES INC.

TOPPING CYCLES

ALL EFFICIENCIES ARE HHV

JAN. 2000

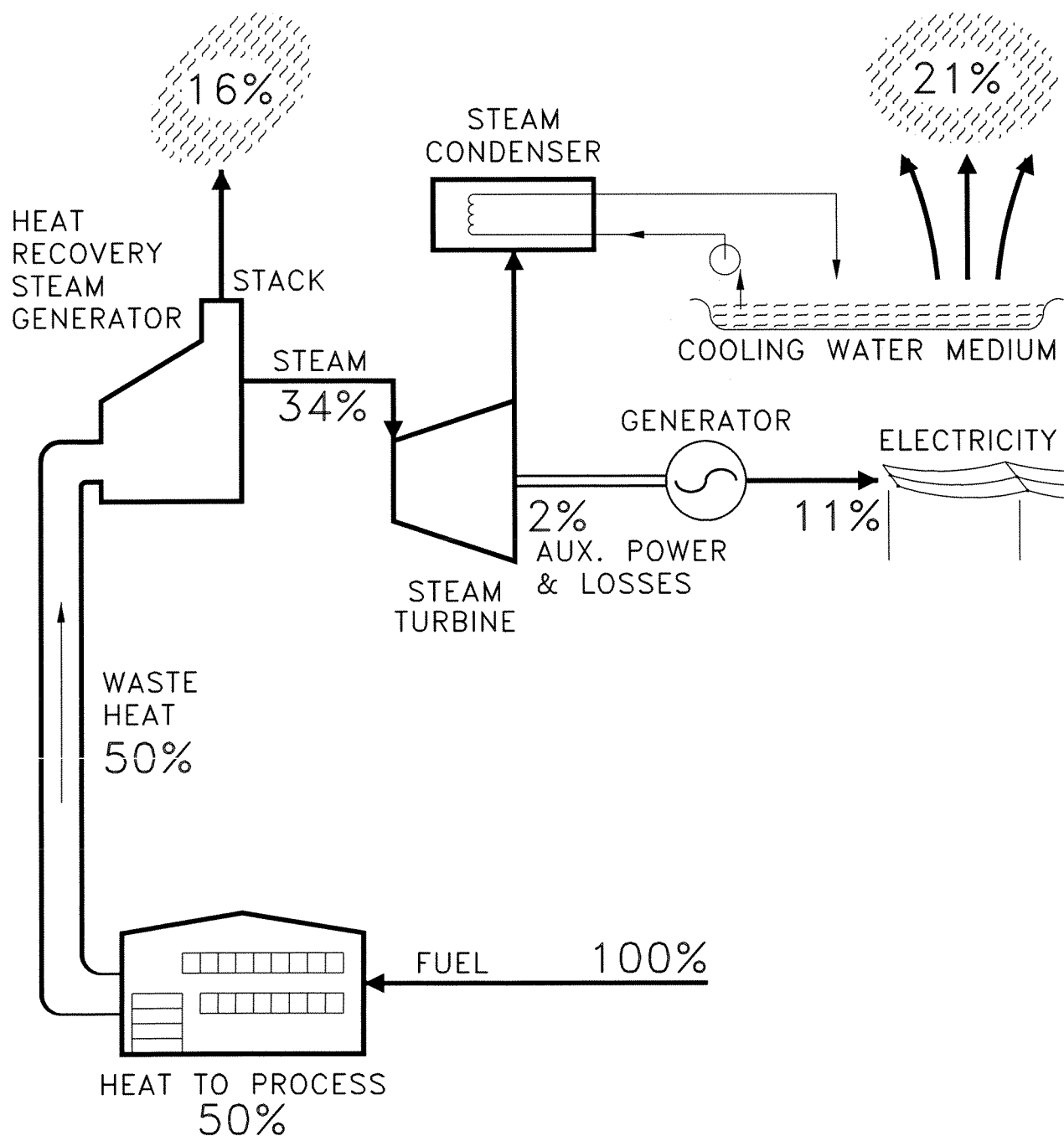
COGENERATION PRINCIPLES
EXHIBIT 1

FUEL → PROCESS HEAT → ELECTRICITY

HRSG/STEAM TURBINE

THERMAL EFFICIENCY = 50 + 11 = 61%

HEAT TO POWER RATIO = 50/11 = 4.5



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BOTTOMING CYCLE

ALL EFFICIENCIES ARE HHV

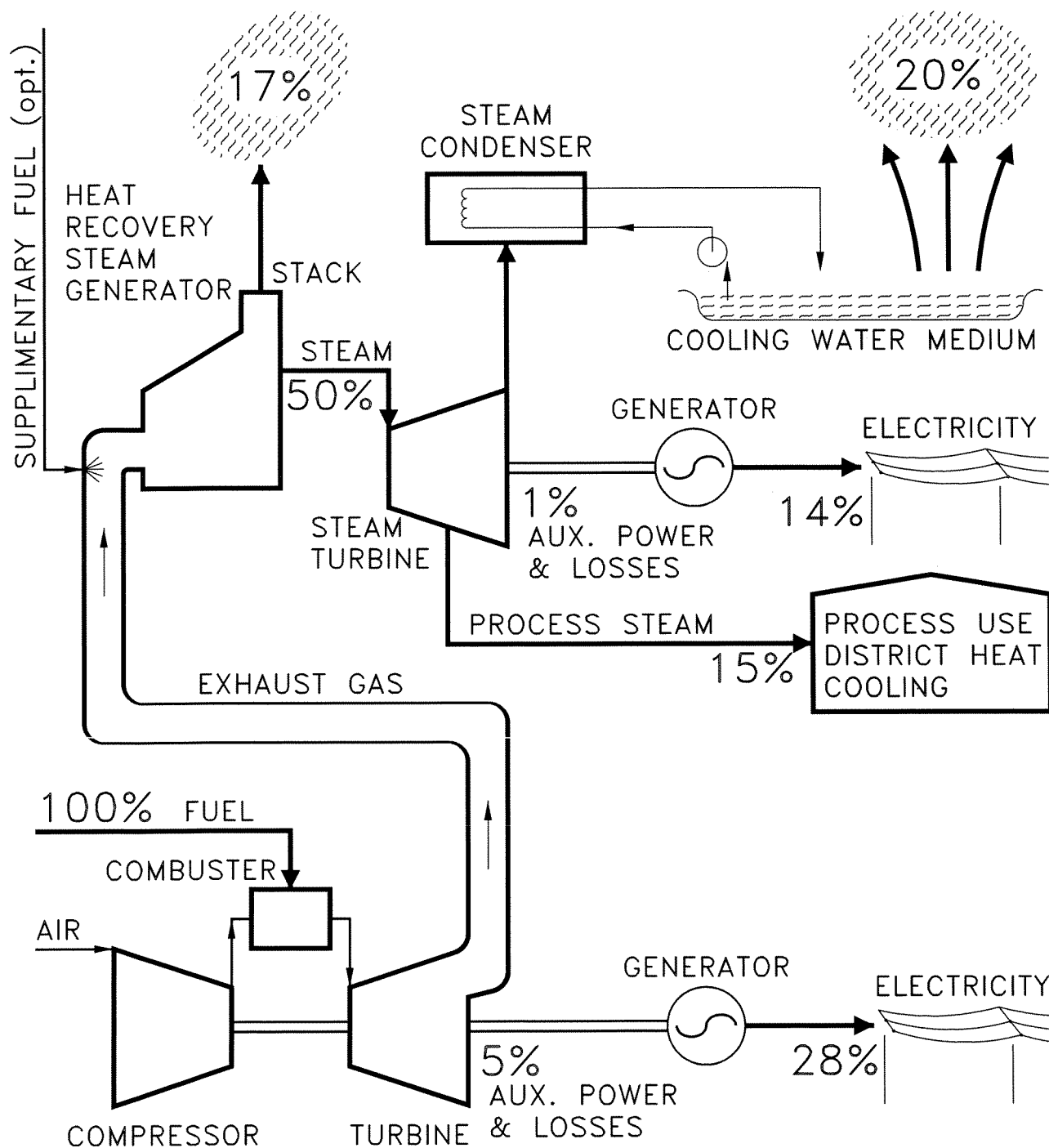
JAN. 2000

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



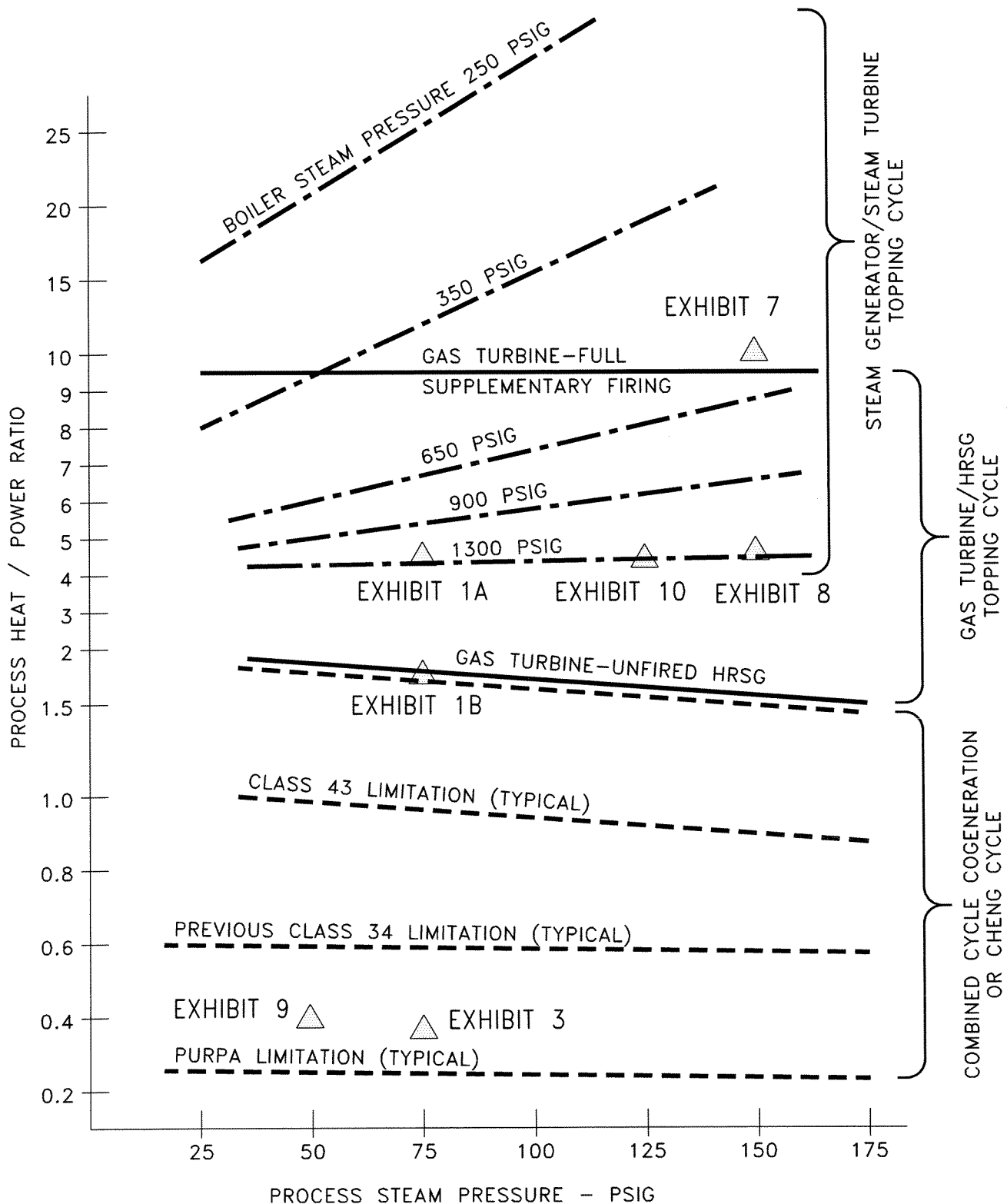
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COMBINED CYCLE COGENERATION

ALL EFFICIENCIES ARE HHV

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COGENERATION PRINCIPLES
EXHIBIT 3



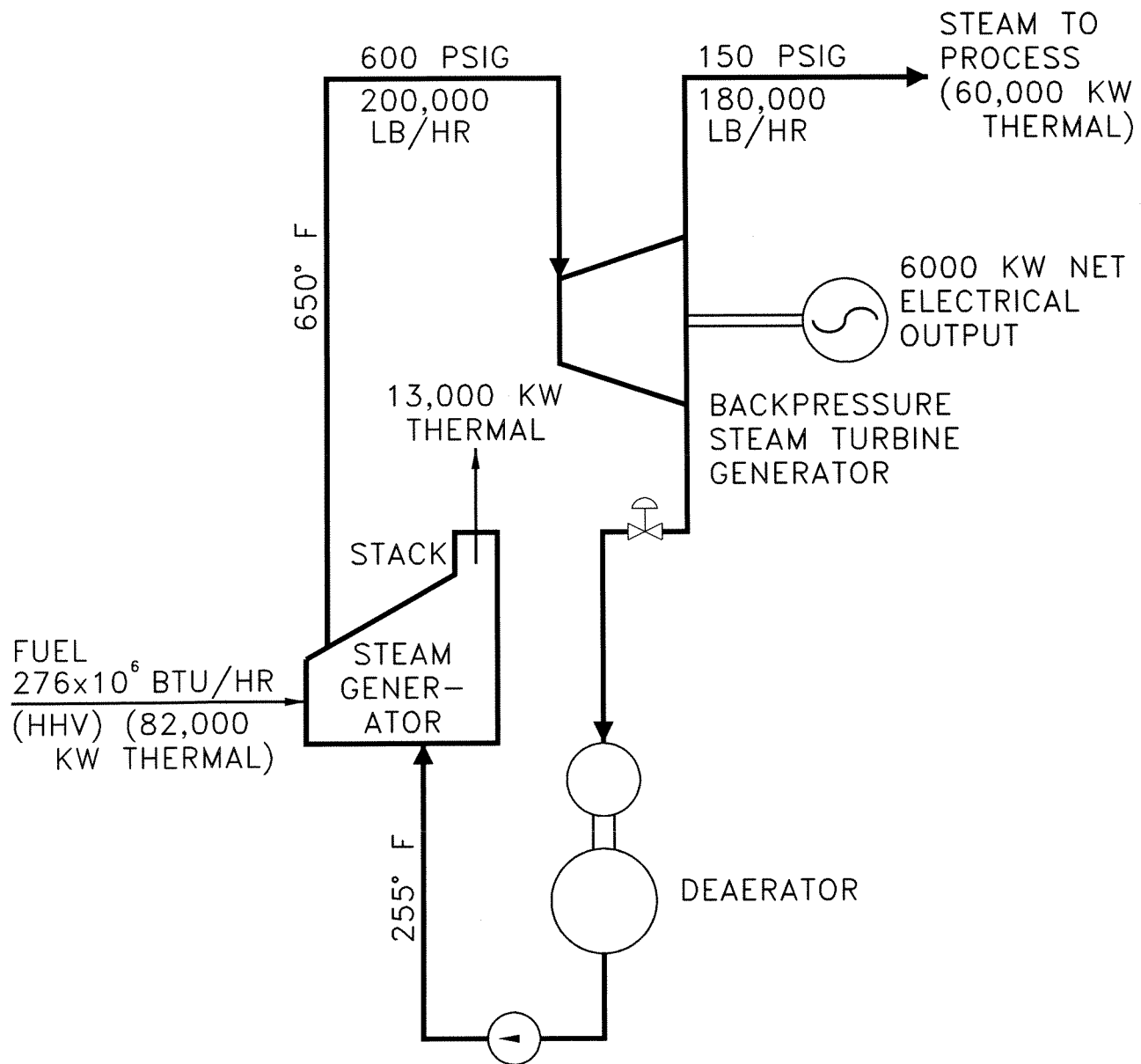
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HEAT TO POWER RATIOS

JAN. 2000

COGENERATION PRINCIPLES
EXHIBIT 4

STEAM GENERATOR/BACKPRESSURE STEAM TURBINE



LOSSES AND AUXILIARY
POWER = 3000 KW

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

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



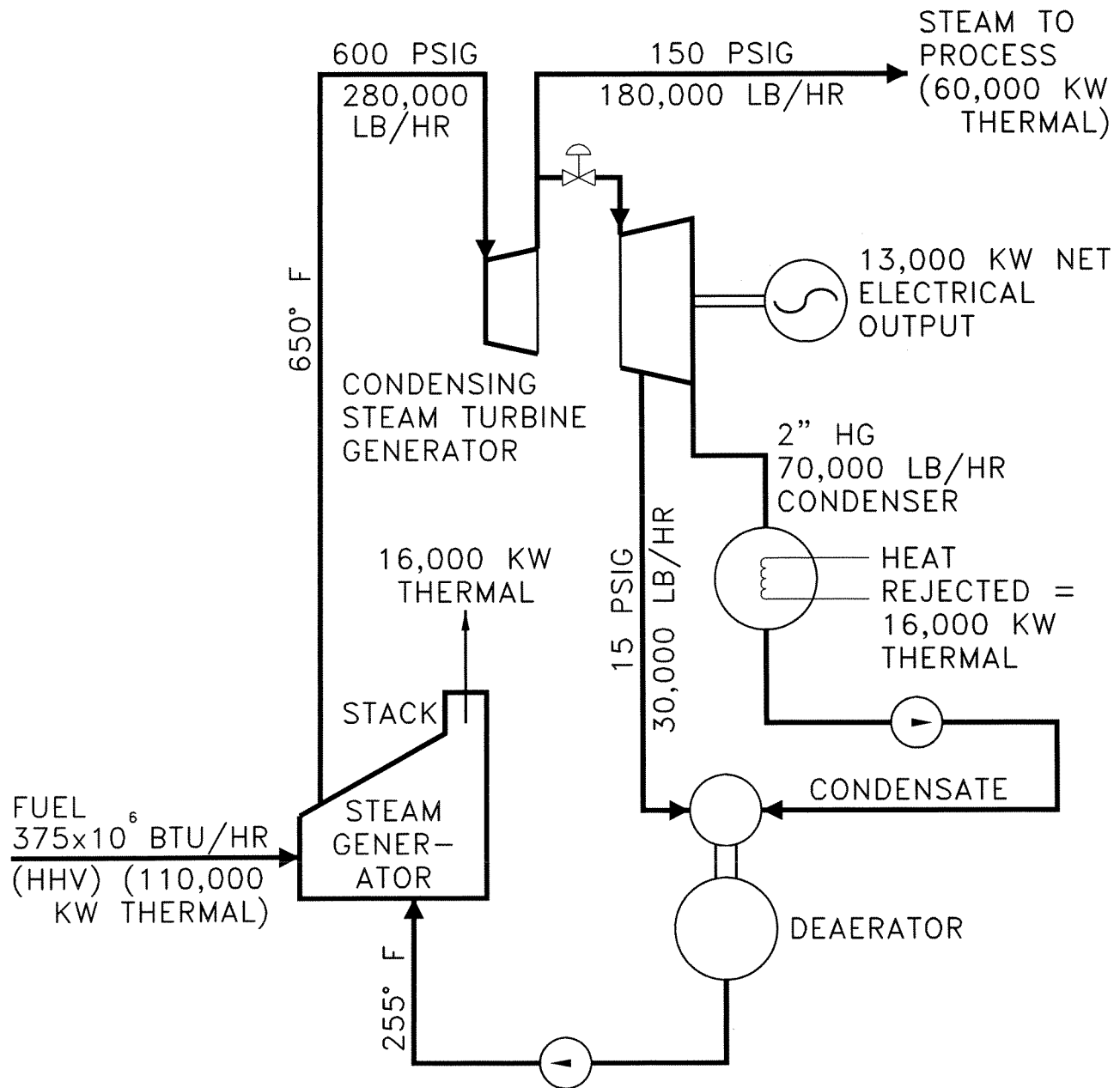
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TYPICAL HEAT BALANCE
ALUMINA PLANT APPLICATION

JAN. 2000

COGENERATION PRINCIPLES
EXHIBIT 5

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**

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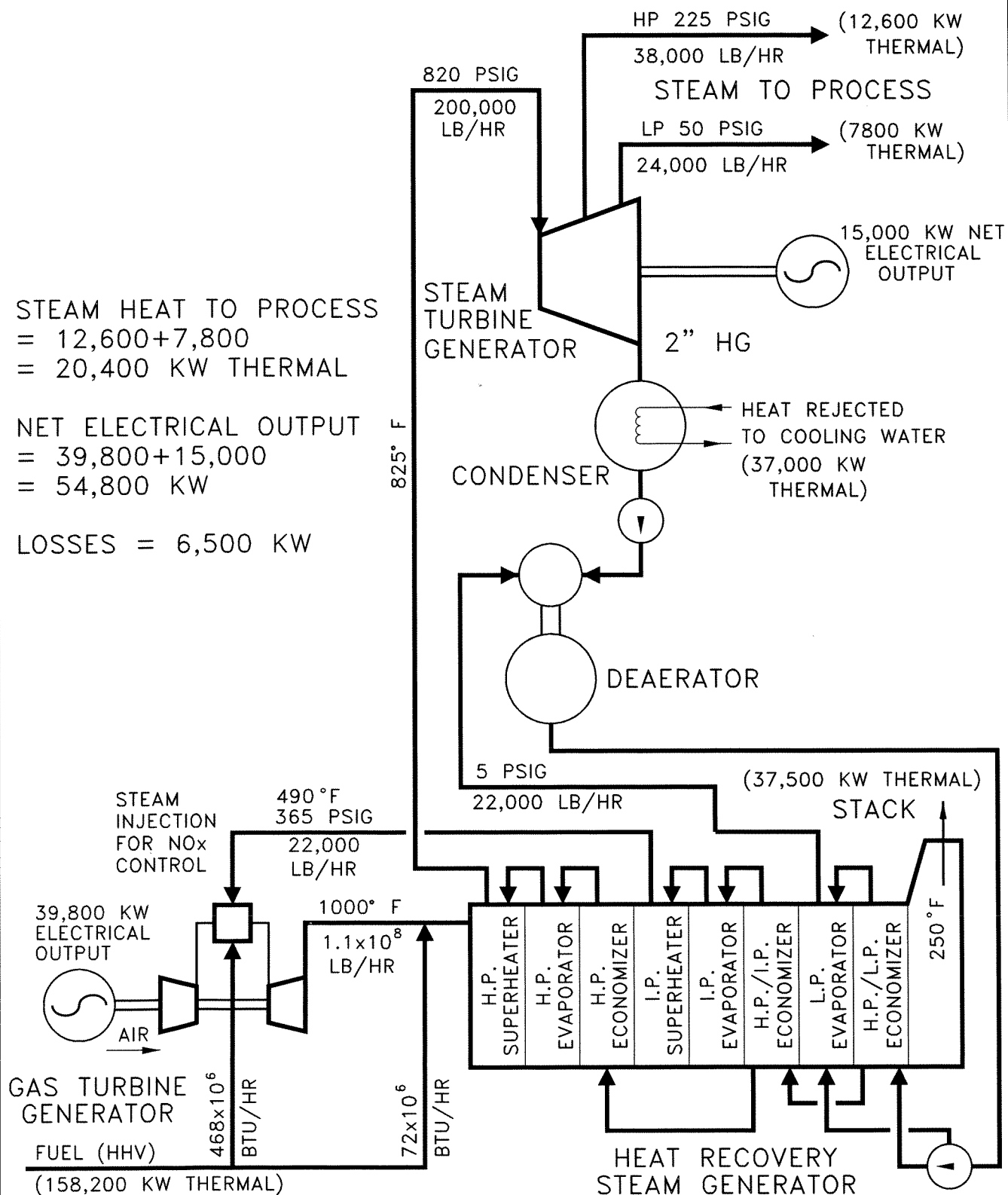
COGENERATION PRINCIPLES
EXHIBIT 6

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



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

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



GRYPHON

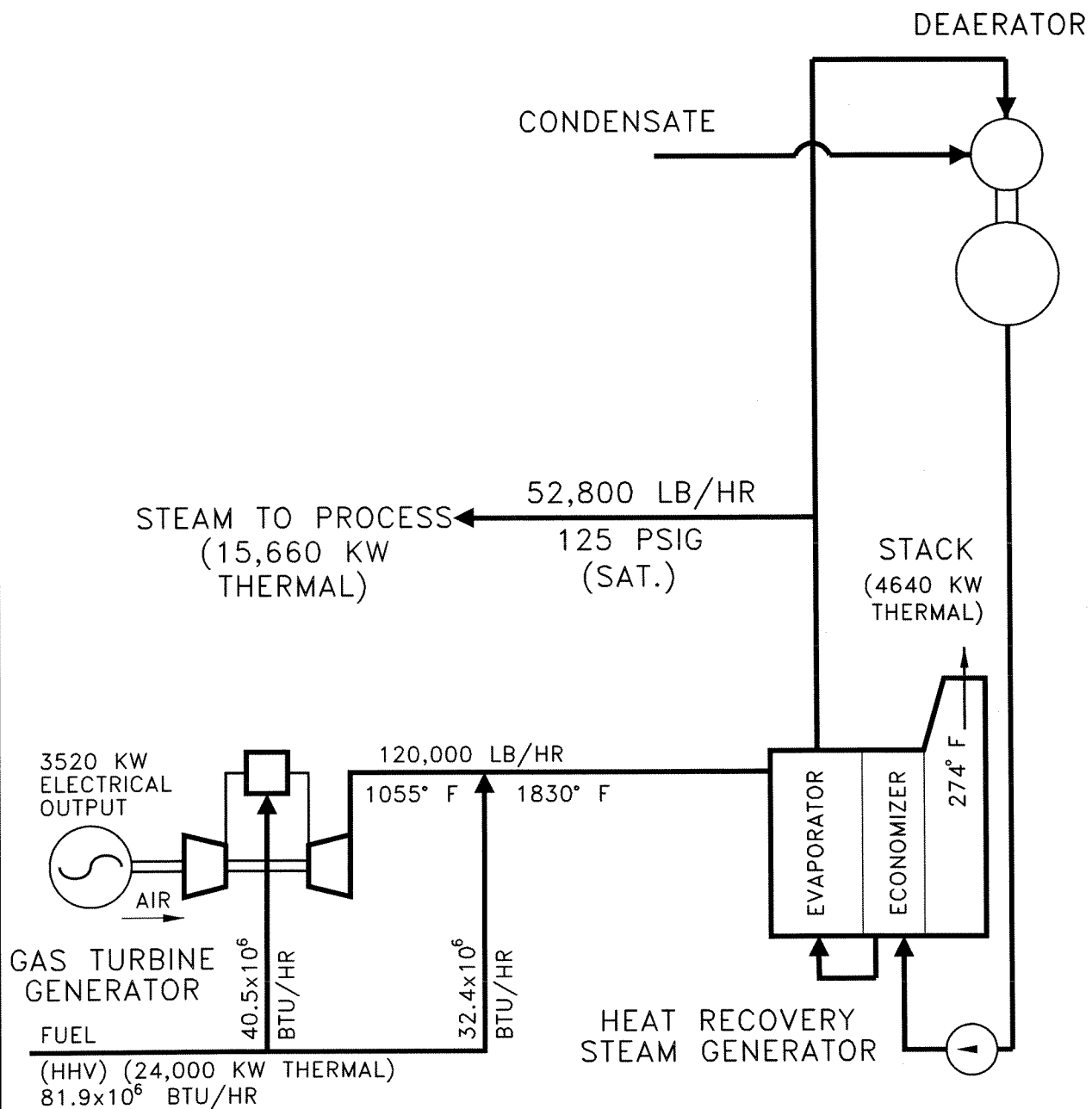
INTERNATIONAL ENGINEERING SERVICES INC.

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

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

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



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INTERNATIONAL ENGINEERING SERVICES INC.

TYPICAL HEAT BALANCE
SMALL PROCESS PLANT APPLICATION

JAN. 2000

COGENERATION PRINCIPLES
EXHIBIT 8