2018 FALL WORKSHOP

Gas Turbine Energy Systems:
Clean and Reliable Energy on Demand

October 23, 2018 | Ottawa

TRAINING SESSION 2
HRSGs, STEAM TURBINES, COGENERATION & COMBINED-CYCLE

A basic introduction to the power plant incorporating gas turbines and related equipment such as heat recovery steam generators (HRSGs) and steam turbines for the cogeneration, combined-cycle or peaking power plant; or repowering.

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Presented at the 2018 Gas Turbines for Energy Network (GTEN) Fall Workshop in Ottawa – October 2018.

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** – where 2 pressure levels of steam are made (high & lower pressures)
- **Triple-Pressure** – where steam is made at 3 different pressure levels
- **Reheat HRSGs** – a multi-pressure HRSG where high pressure steam is re-introduced to the HRSG after it has expanded in a steam turbine, and reheated towards the original high-pressure steams 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.

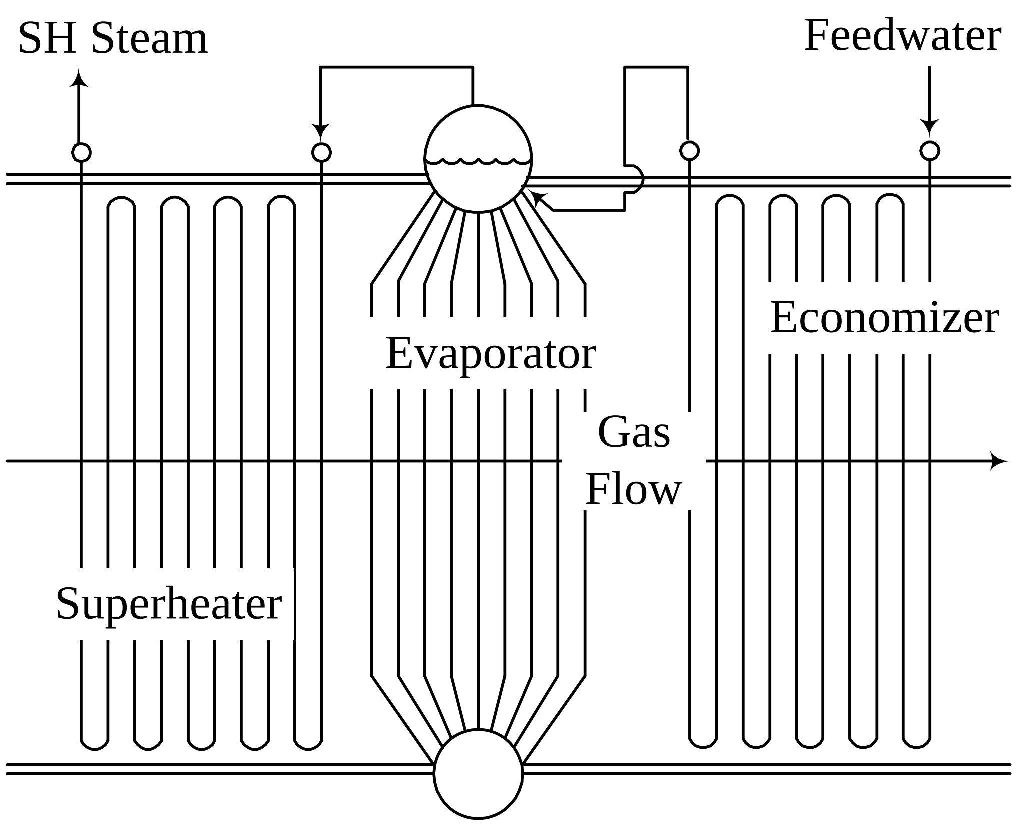
Emissions controls can be integrated into HRSGs, if needed.

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
- **Economizer** section – adds sensible heat (temperature) to incoming feedwater.

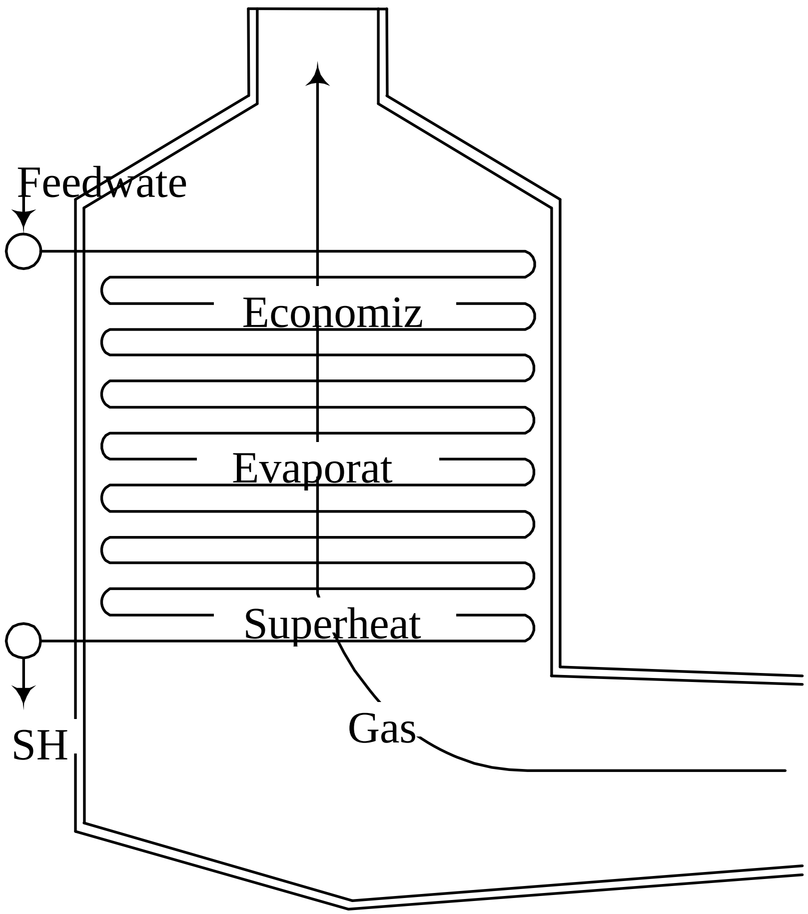
The feedwater/steam flows in reverse to the turbine exhaust gases.



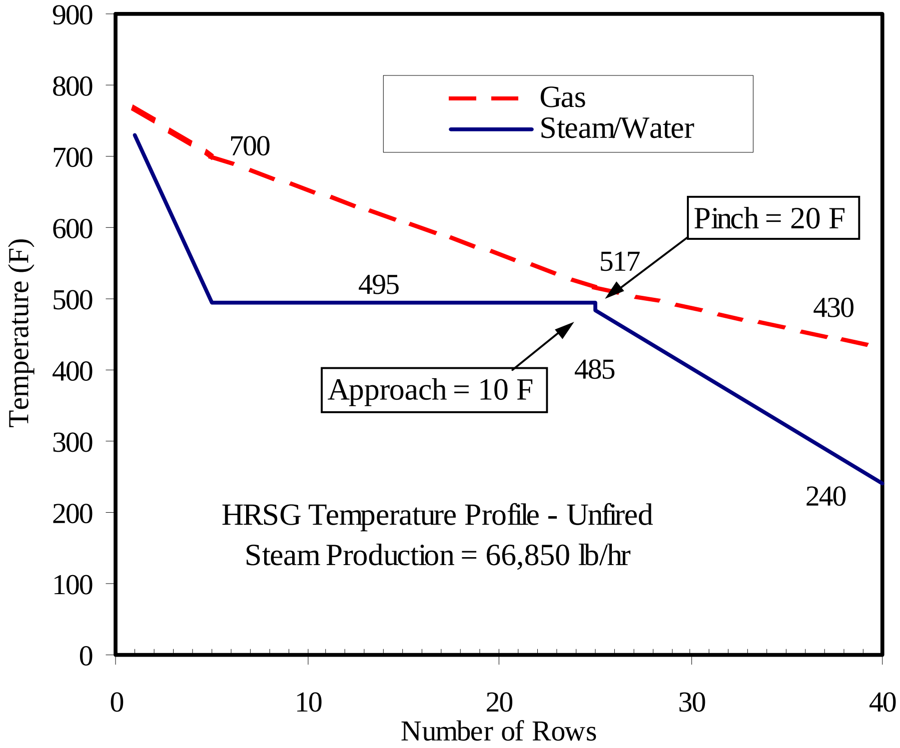
Once-Through Steam Generator (No Drums)

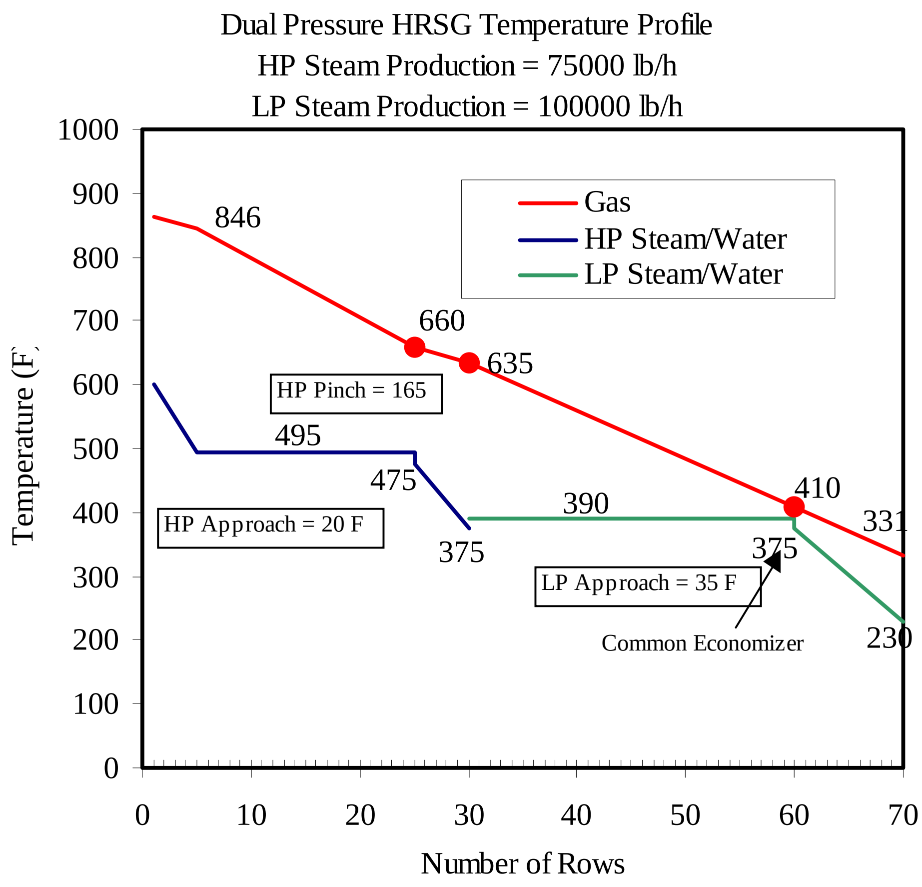
OTSGs were previously manufactured by Innovative Steam Technologies (IST) in Cambridge, Ontario. OTSGs can run "dry" meaning no water/steam in the tube banks.

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



Typical HRSG Temperature Profiles

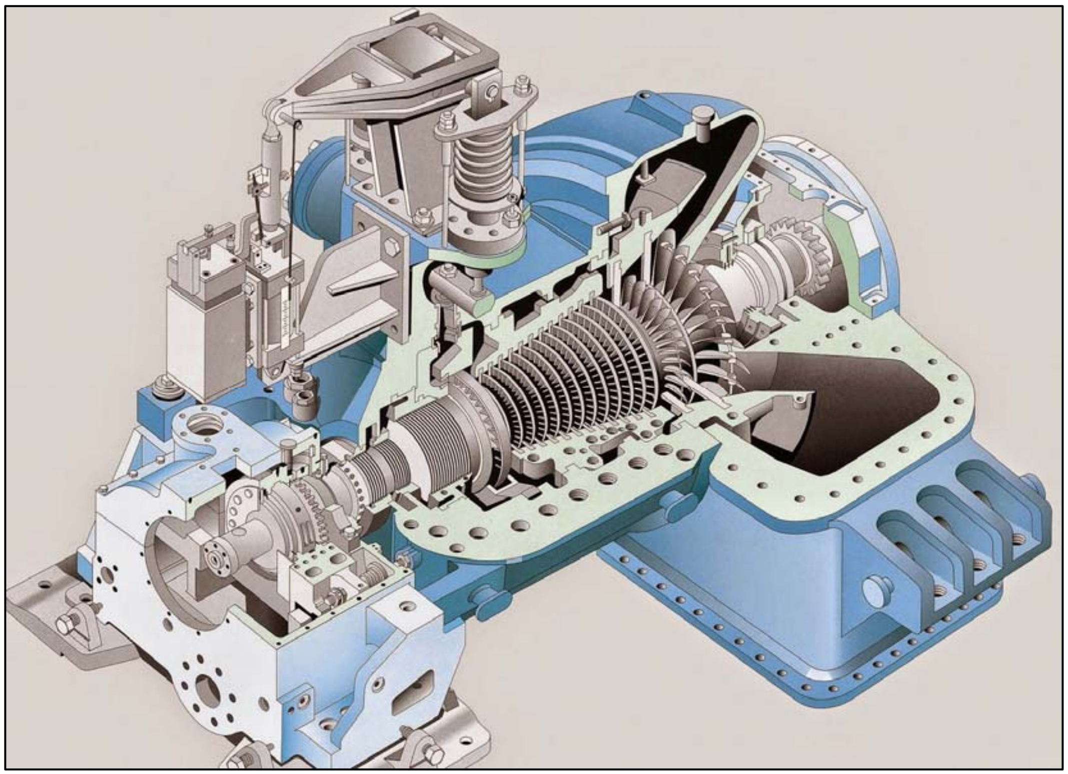


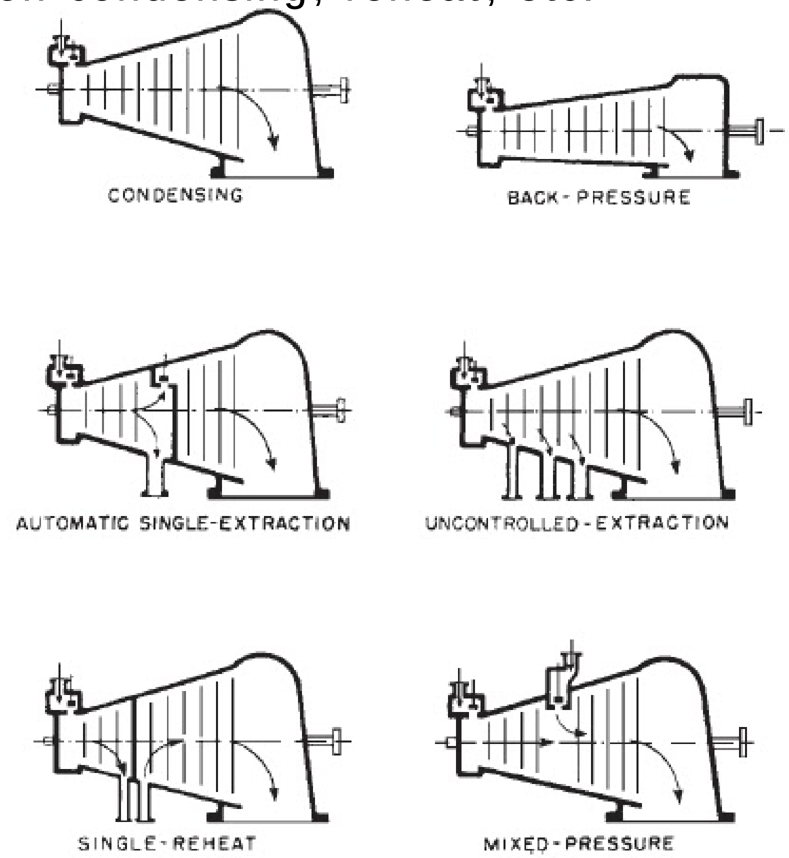


STEAM TURBINES

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

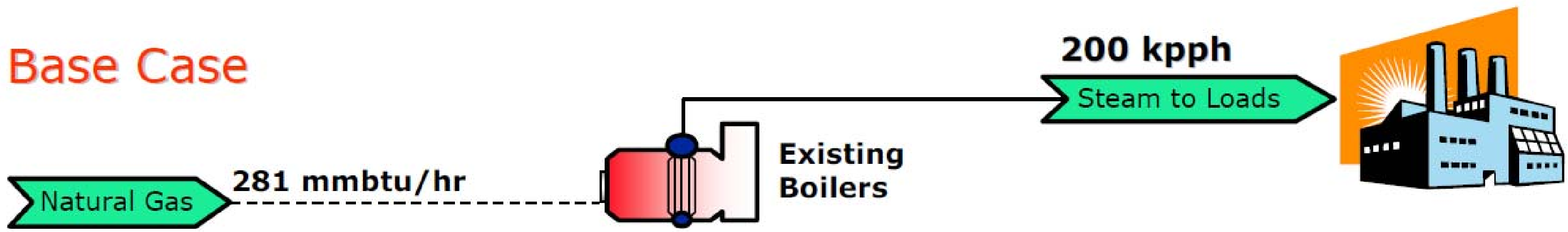
- **Backpressure** steam turbines make electricity & release steam to process.
- **Condensing** steam turbines make electricity only.
- **Extraction** steam turbines make electricity & release steam to process.
- Variations include extraction-condensing; admission-condensing; reheat; etc.





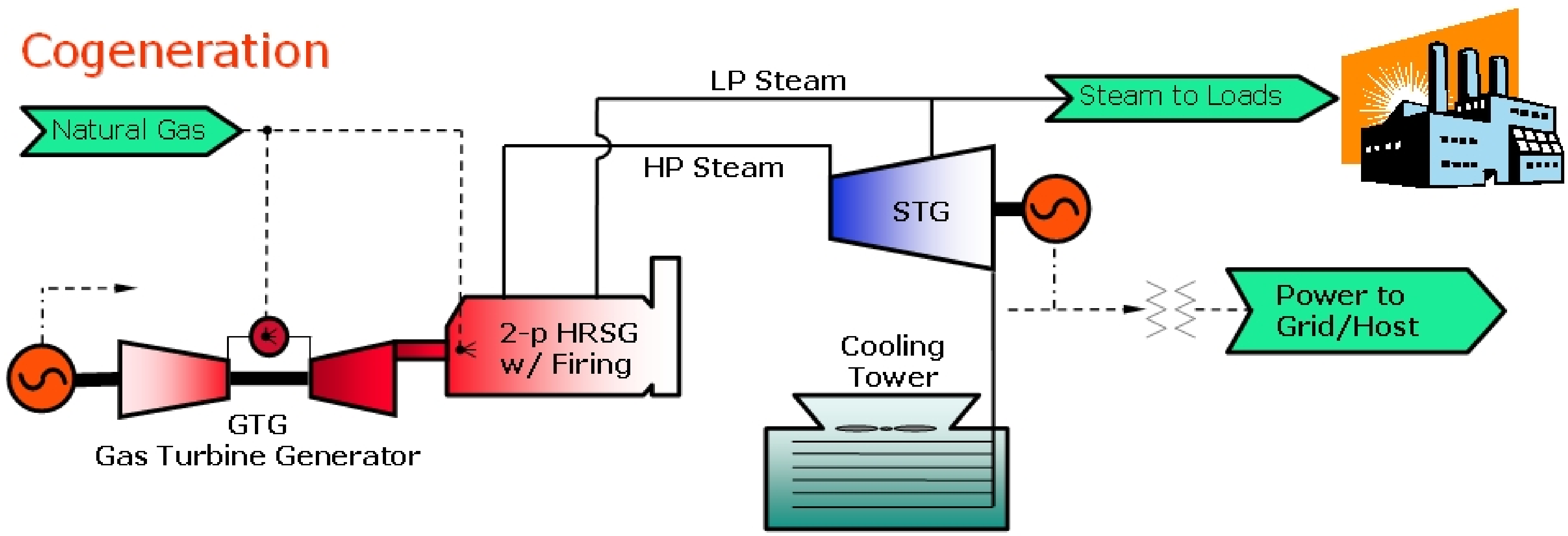
SHP / SEPARATE HEAT-AND-POWER:

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

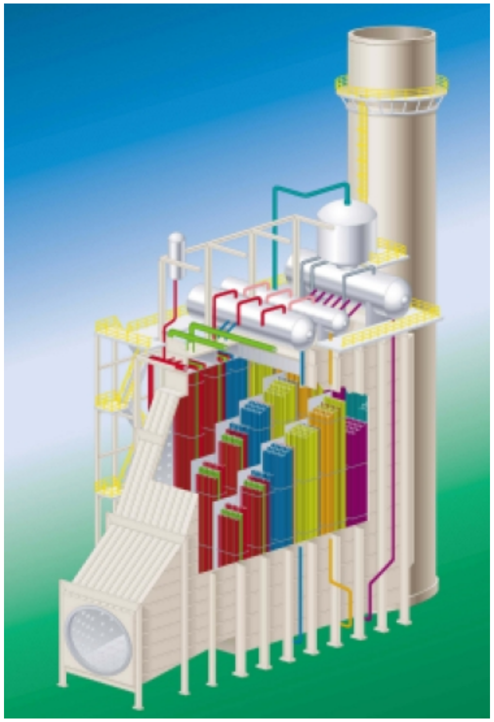


CHP / COGENERATION:

"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"

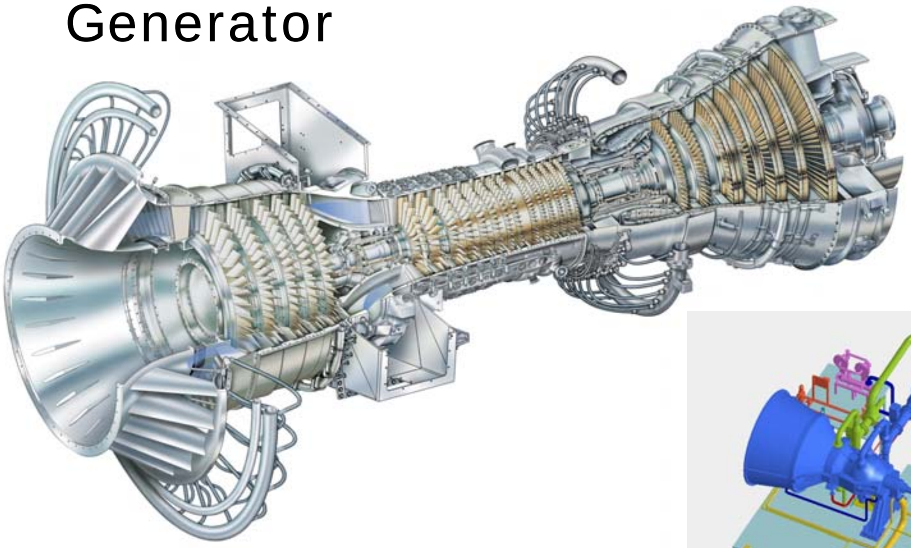


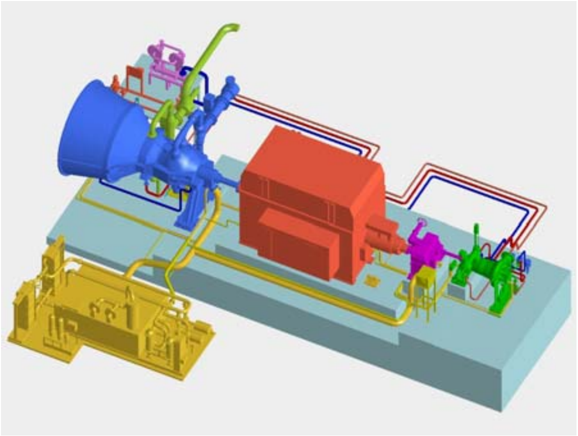
MAJOR EQUIPMENT



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





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

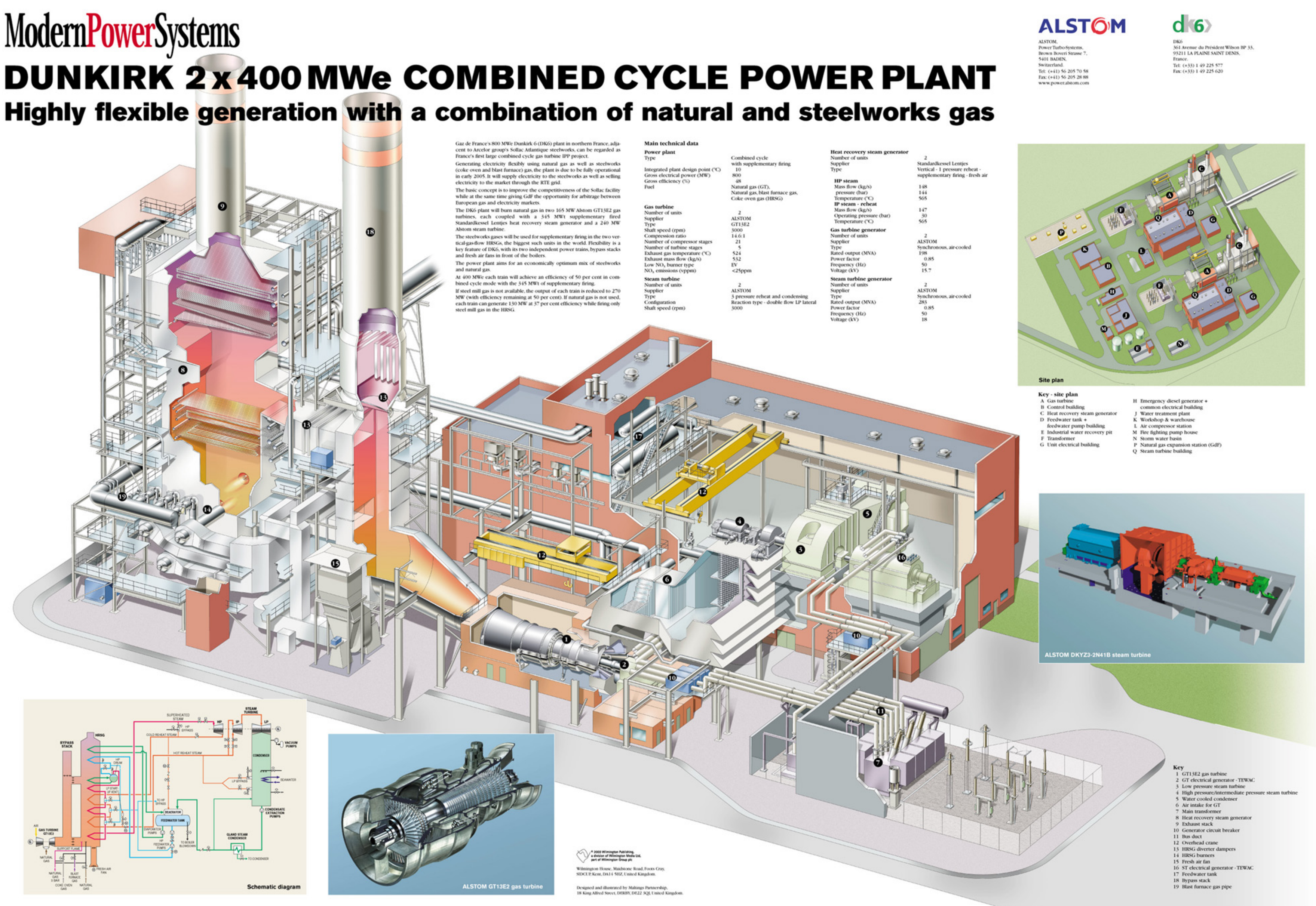
West Windsor Power – Windsor

TransCanada Energy – Halton Hills Generating Station

Goreway Station Power – Toronto

Portlands Energy Centre – Toronto

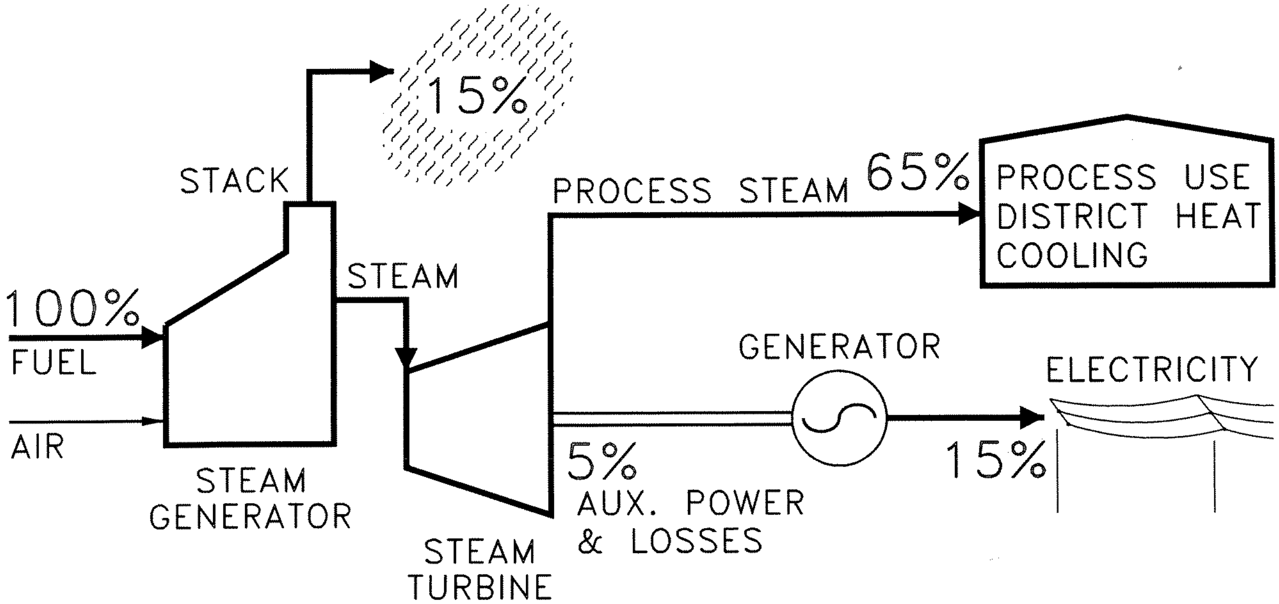
HRSGS, STEAM TURBINES, COGENERATION & COMBINED-CYCLE ©



FUEL ⟶ ELECTRICITY ⟶ PROCESS HEAT

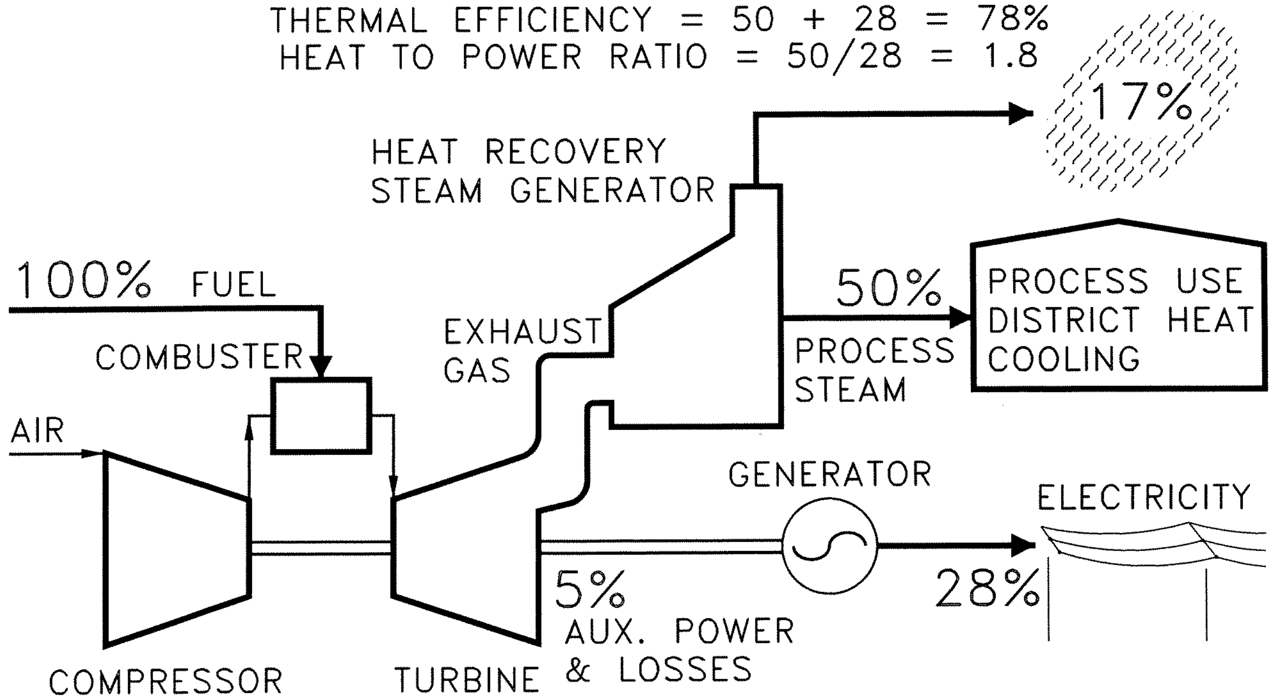
A. STEAM GENERATOR/STEAM TURBINE

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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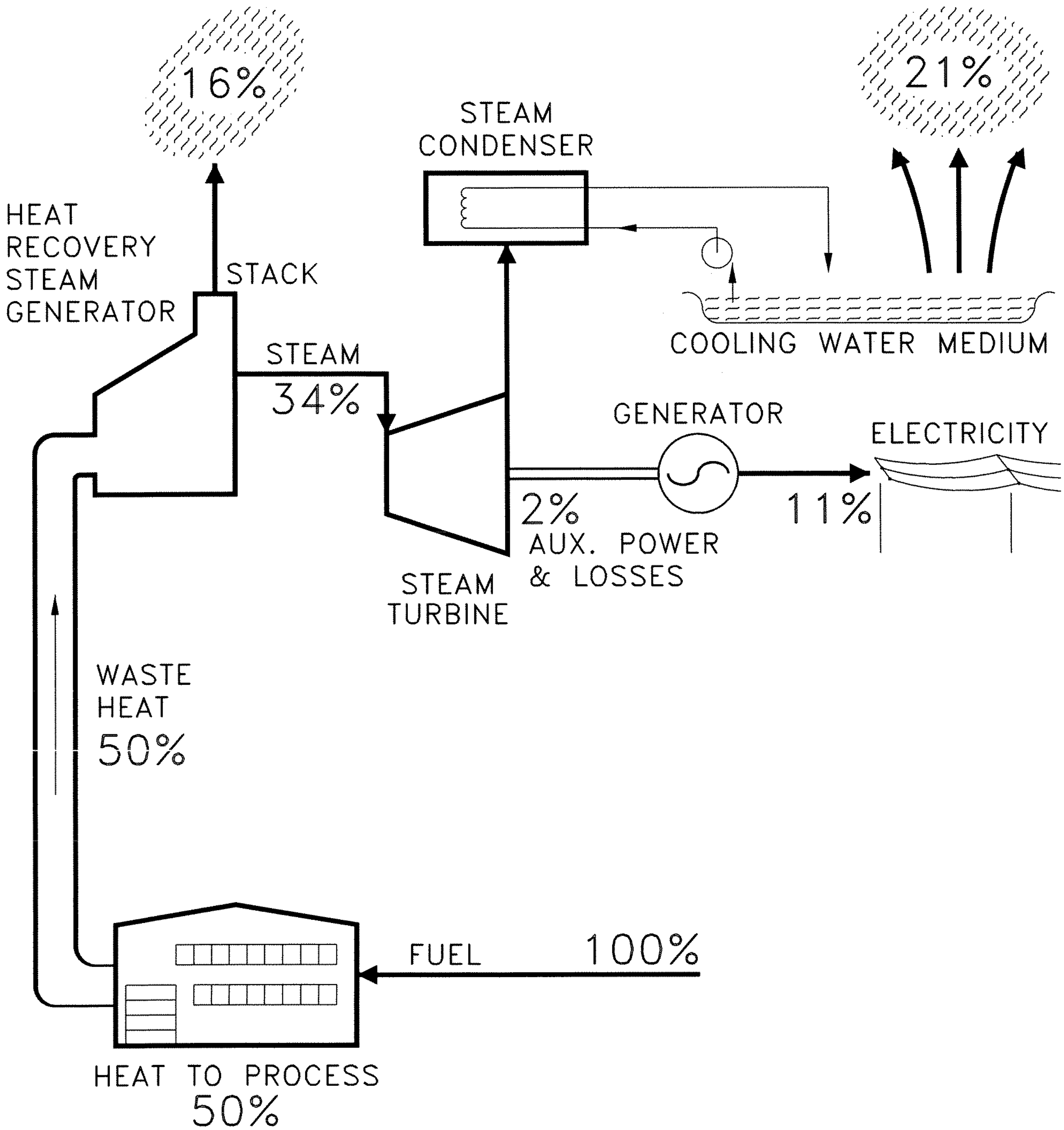
TOPPING CYCLES	
JAN. 2000	COGENERATION PRINCIPLES EXHIBIT 1

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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INTERNATIONAL ENGINEERING SERVICES INC.

BOTTOMING CYCLE

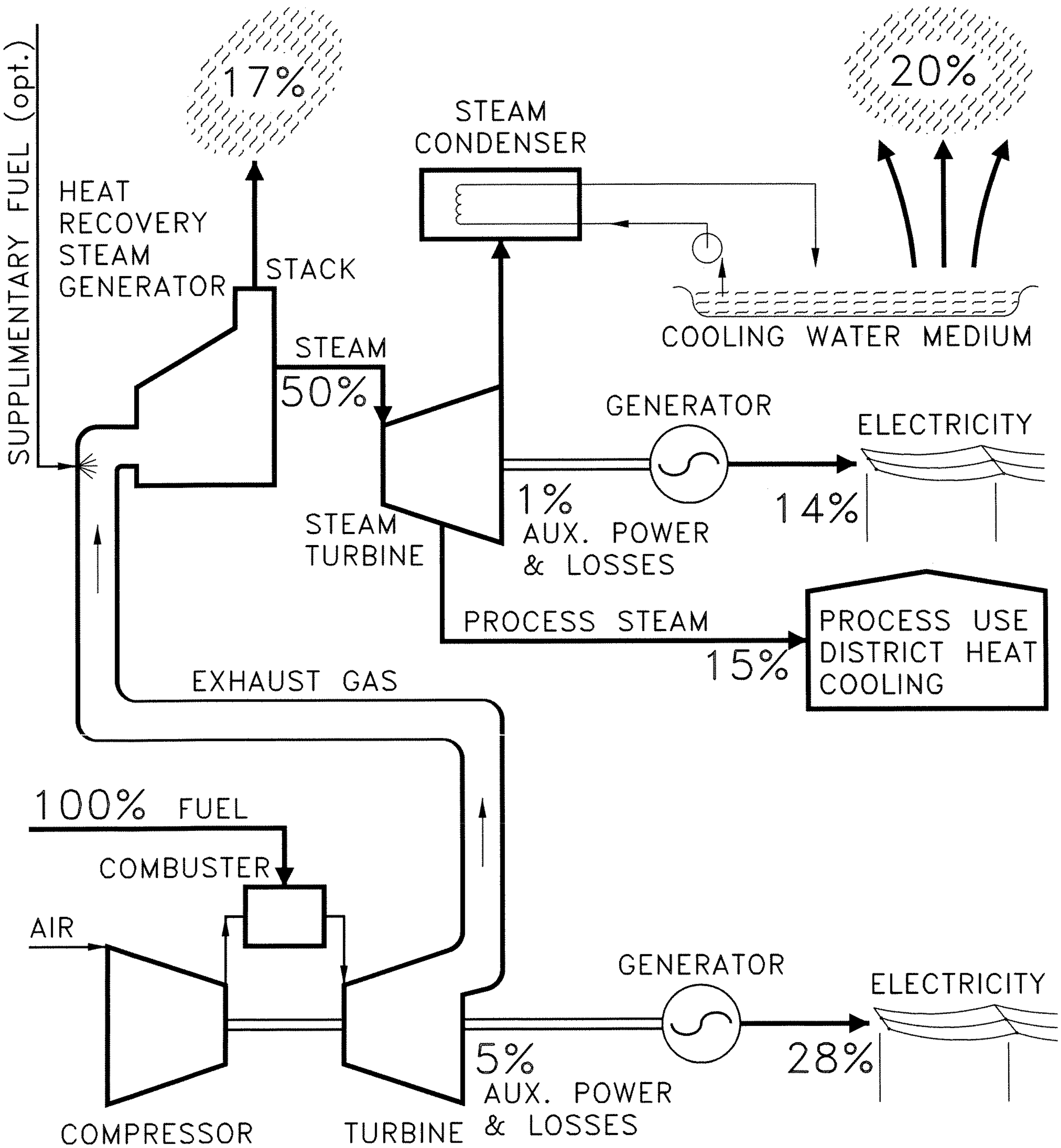
JAN. 2000	COGENERATION PRINCIPLES EXHIBIT 2

FUEL ⟶ ELECTRICITY ⟶ PROCESS ⟶ ELECTRICITY

GAS TURBINE/HRSG/STEAM TURBINE

THERMAL EFFICIENCY = 28 + 15 +14 = 57%

HEAT TO POWER RATIO = 15/(28 + 14) = 0.36



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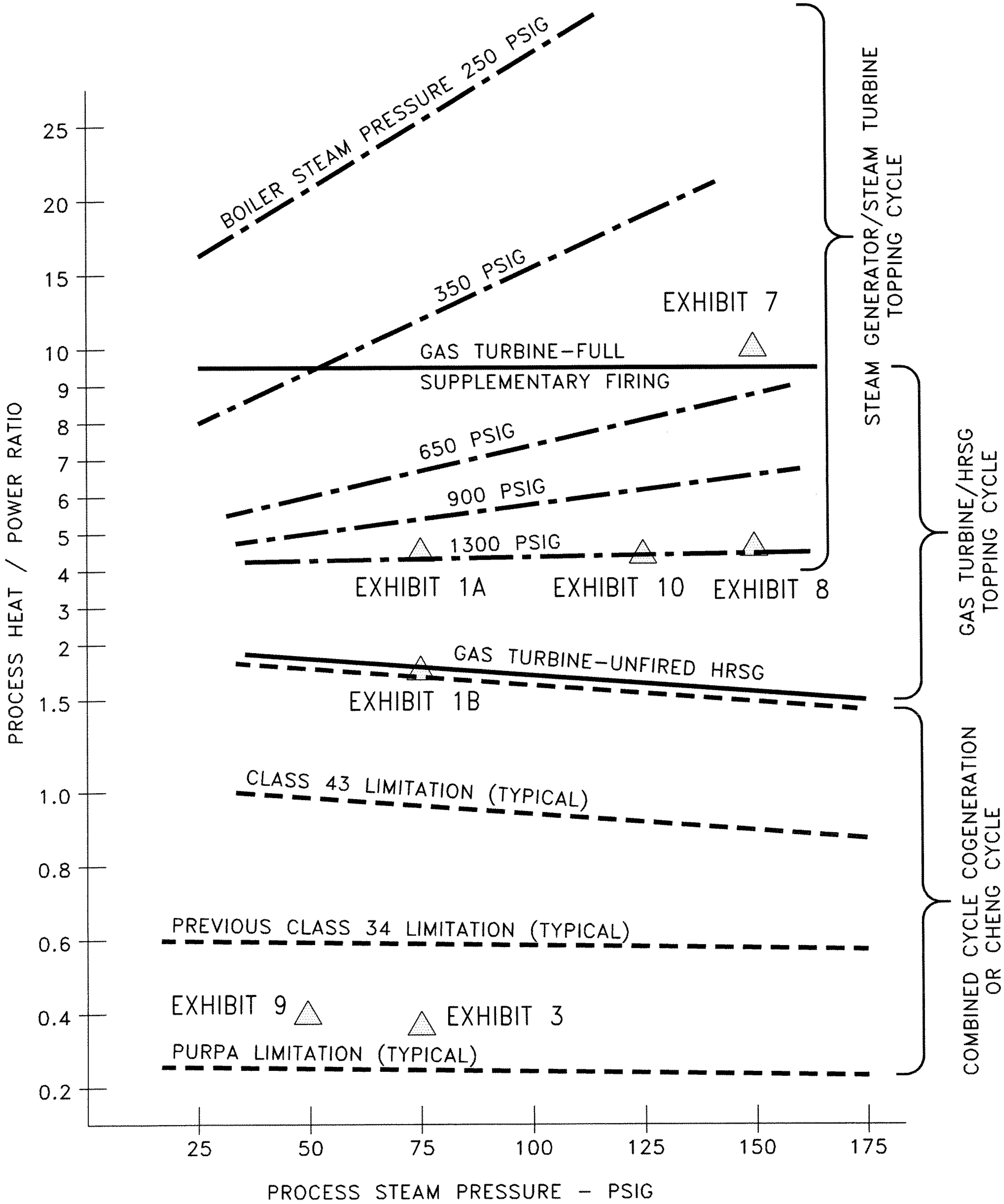
COMBINED CYCLE COGENERATION

ALL EFFICIENCIES ARE HHV

JAN. 2000	COGENERATION PRINCIPLES EXHIBIT 3



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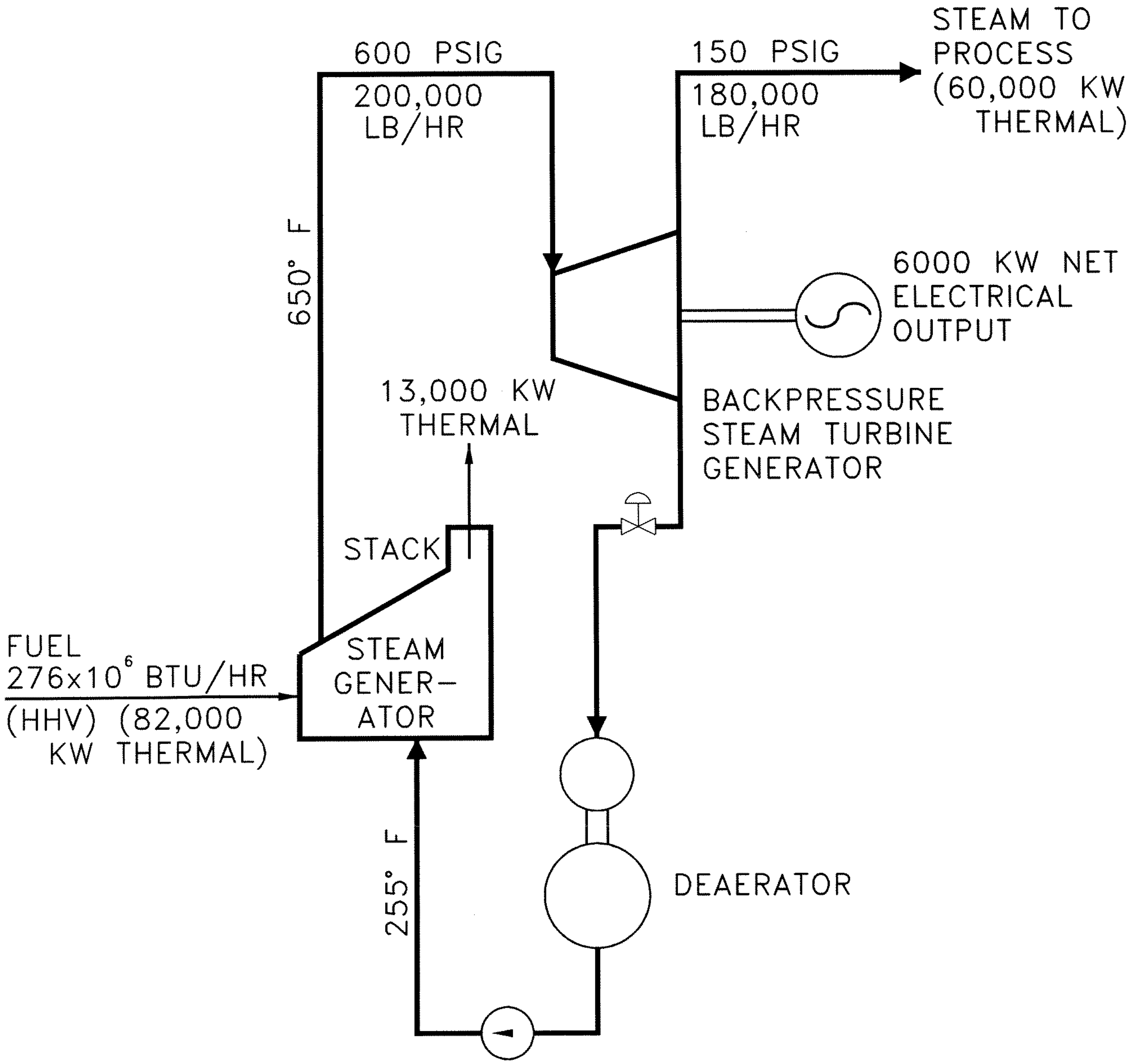
HEAT TO POWER RATIOS

JAN. 2000	COGENERATION PRINCIPLES EXHIBIT 4

STEAM GENERATOR/BACKPRESSURE STEAM TURBINE



LOSSES AND AUXILIARY POWER = 3000 KW

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

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

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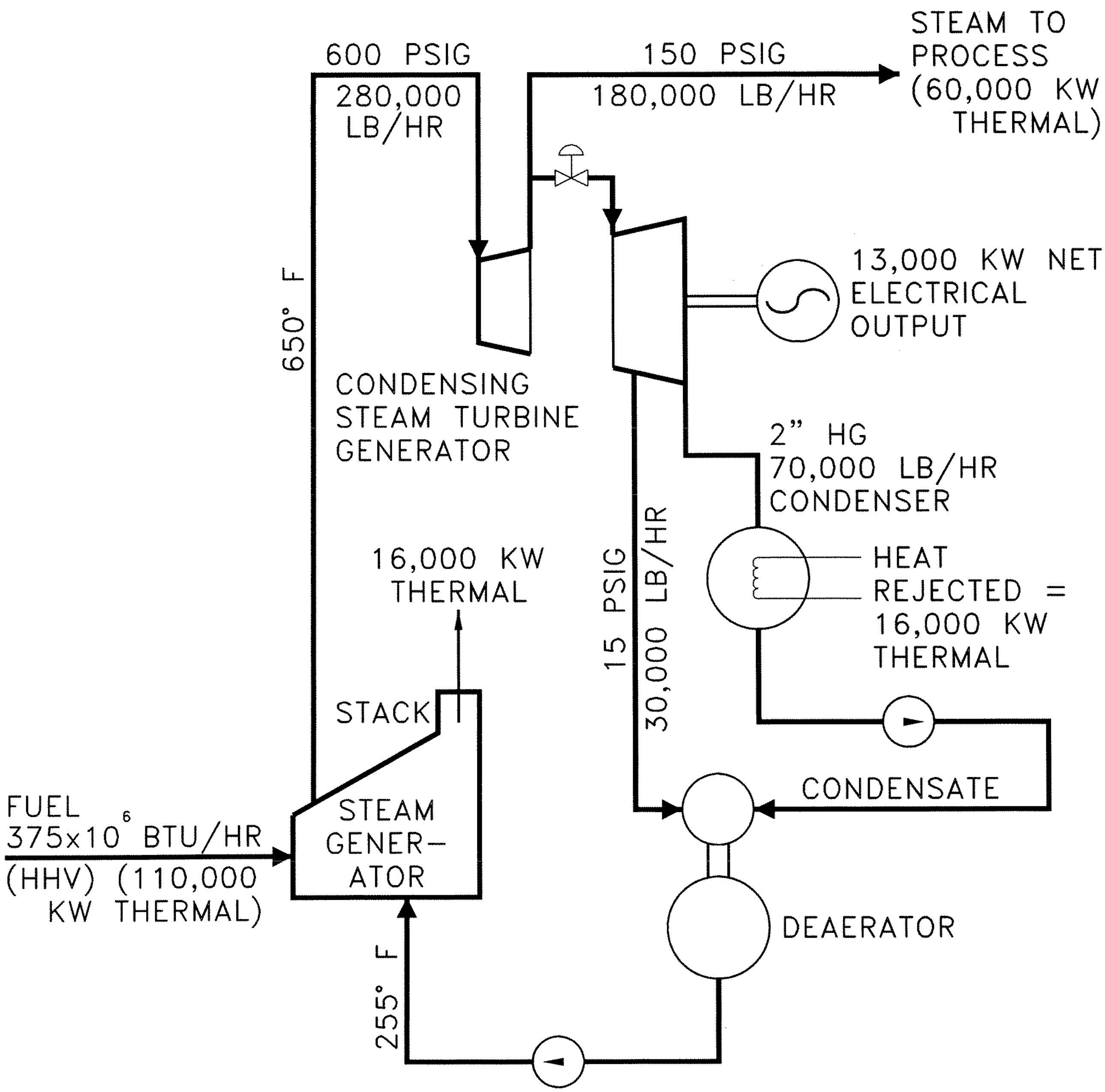
TYPICAL HEAT BALANCE
ALUMINA PLANT APPLICATION

JAN. 2000	COGENERATION PRINCIPLES EXHIBIT 5

STEAM GENERATOR/CONDENSING STEAM TURBINE



LOSSES AND AUXILIARY POWER = 5000 KW

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

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

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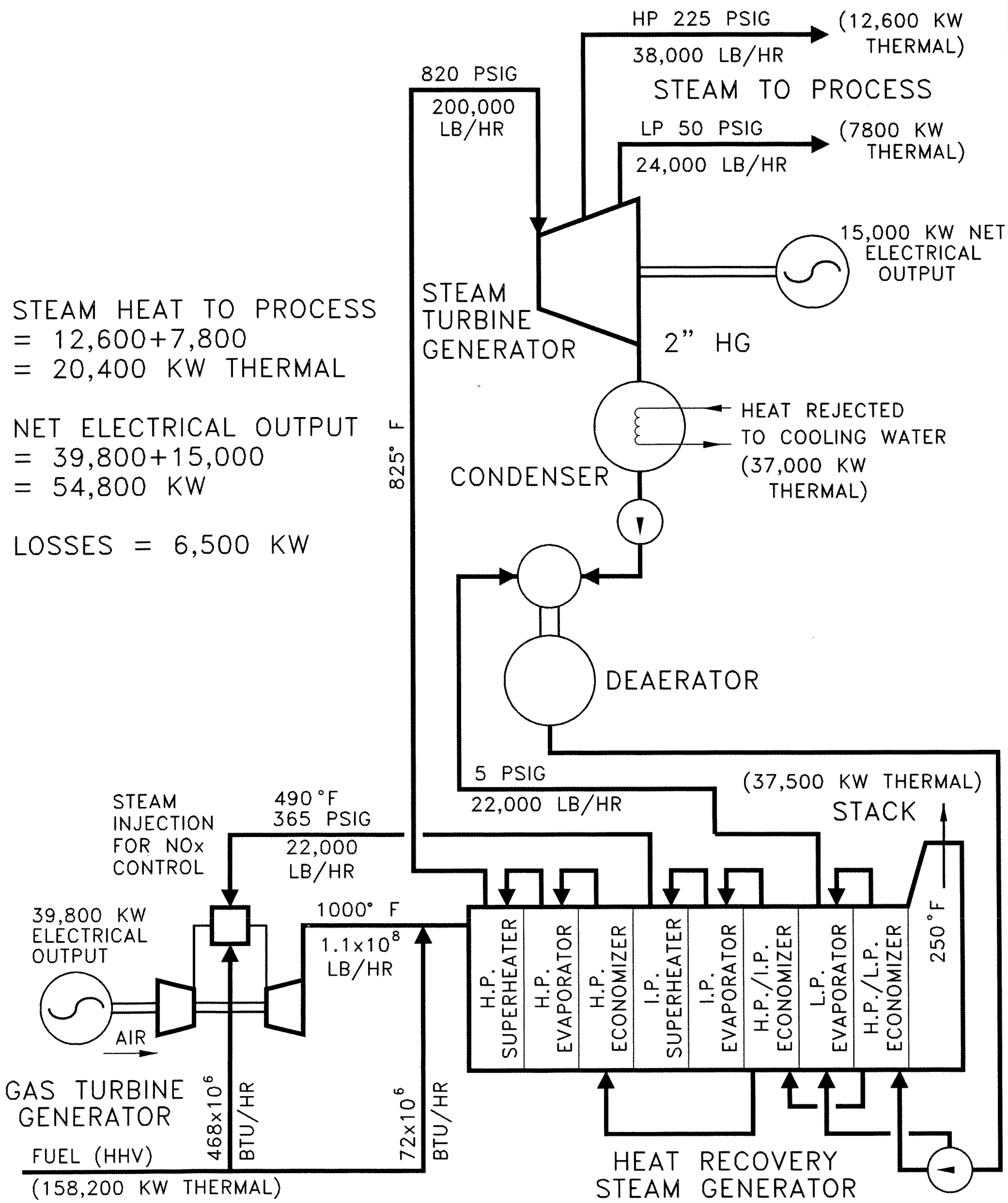
TYPICAL HEAT BALANCE PULP & PAPER APPLICATION

JAN. 2000	COGENERATION PRINCIPLES EXHIBIT 6

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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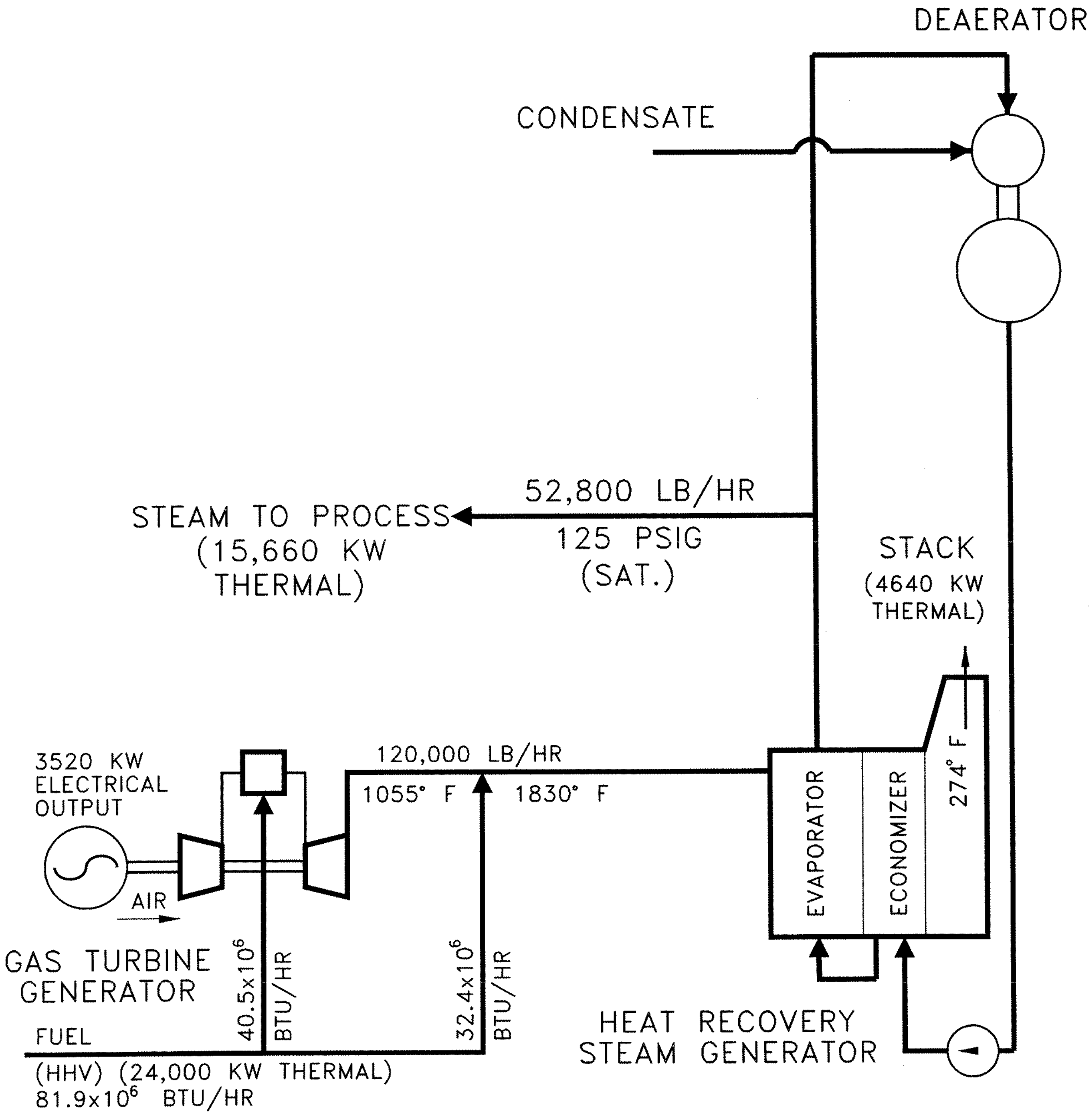
TYPICAL HEAT BALANCE
COMBINED CYCLE APPLICATION

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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TYPICAL HEAT BALANCE SMALL PROCESS PLANT APPLICATION

JAN. 2000

COGENERATION PRINCIPLES EXHIBIT 8