OPTIMAL INTEGRATION OF STEAM TURBINES IN INDUSTRIAL PROCESS PLANTS

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DEFINITIONS: CHP & EFFICIENCY

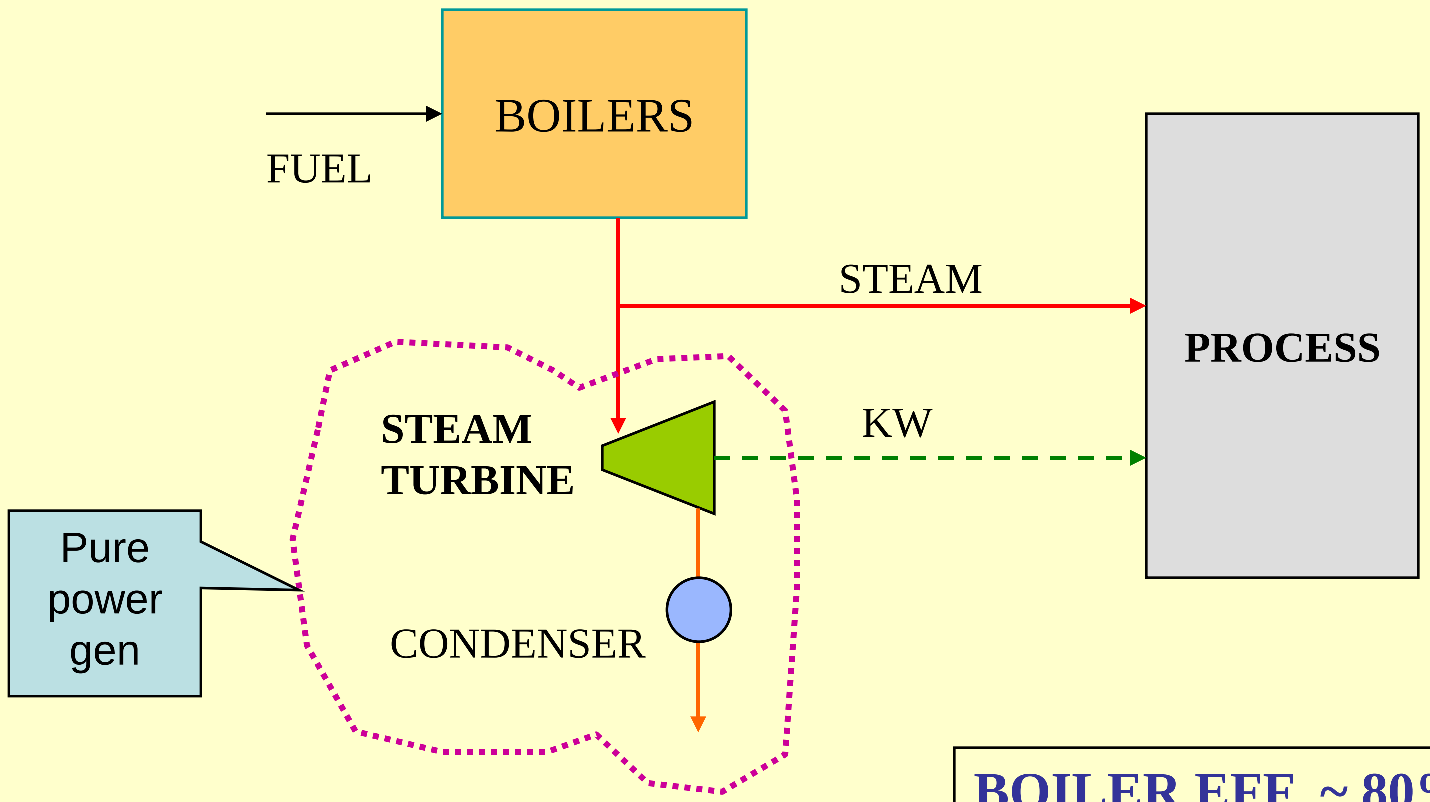
- CHP = **C**ombined **H**eat and **P**ower (= energy utility system for the plant site)
- Steam Turbines are <u>Heat Engines</u> that operate on the Rankine cycle. They convert DP into Shaftwork; a generator then converts Shaftwork into Elec power
- Thermodynamic Efficiency is defined as

$$\frac{\text{Useful Energy Output}}{\text{Energy Input}}$$

- For Generation, 1 useful output = Power only. Machine eff = ~20%, System Eff = ~35%
- For Cogeneration, 2 useful outputs = Power + Process Heat, Machine eff = ~20%, but System Eff ~75-80%

This is CHP, but <u>not</u> Cogeneration

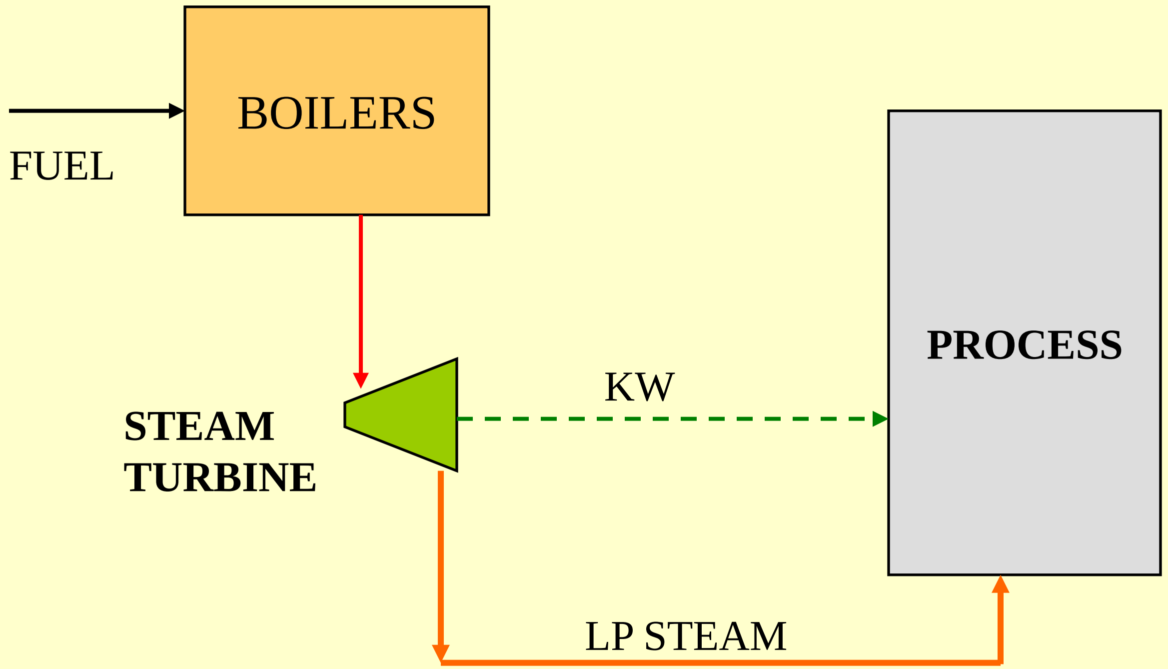
LATENT HEAT OF ST EXHAUST IS <u>WASTED</u>



BOILER EFF ~ 80%
POWER GEN EFF < 25%

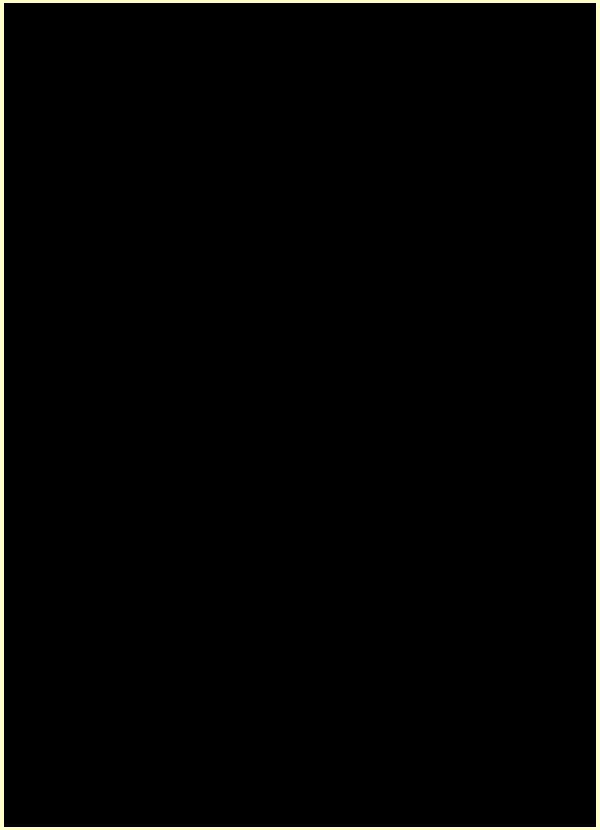
This is both CHP and "Co-Generation"

LAT HT OF EXHAUST STM IS USED IN THE PROCESS

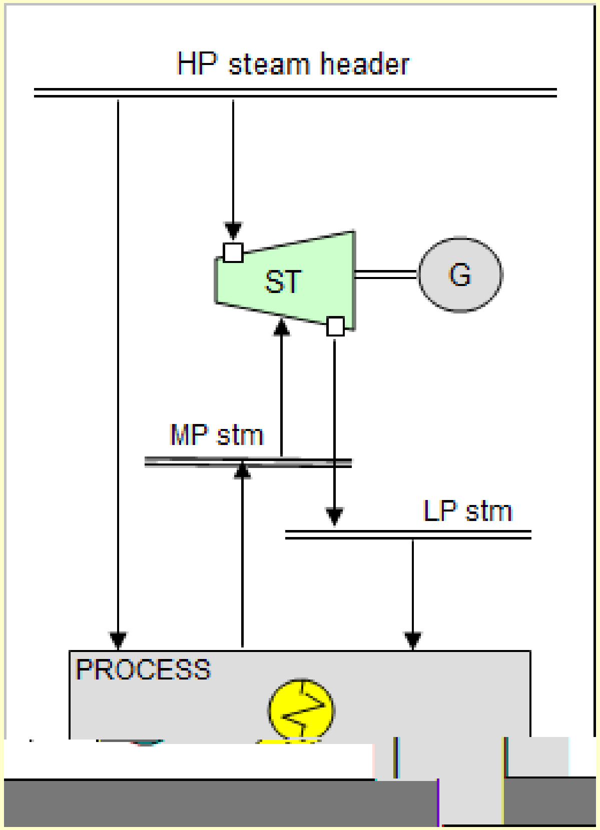


OVERALL EFF ~ 75%

Alternative Cogen configurations



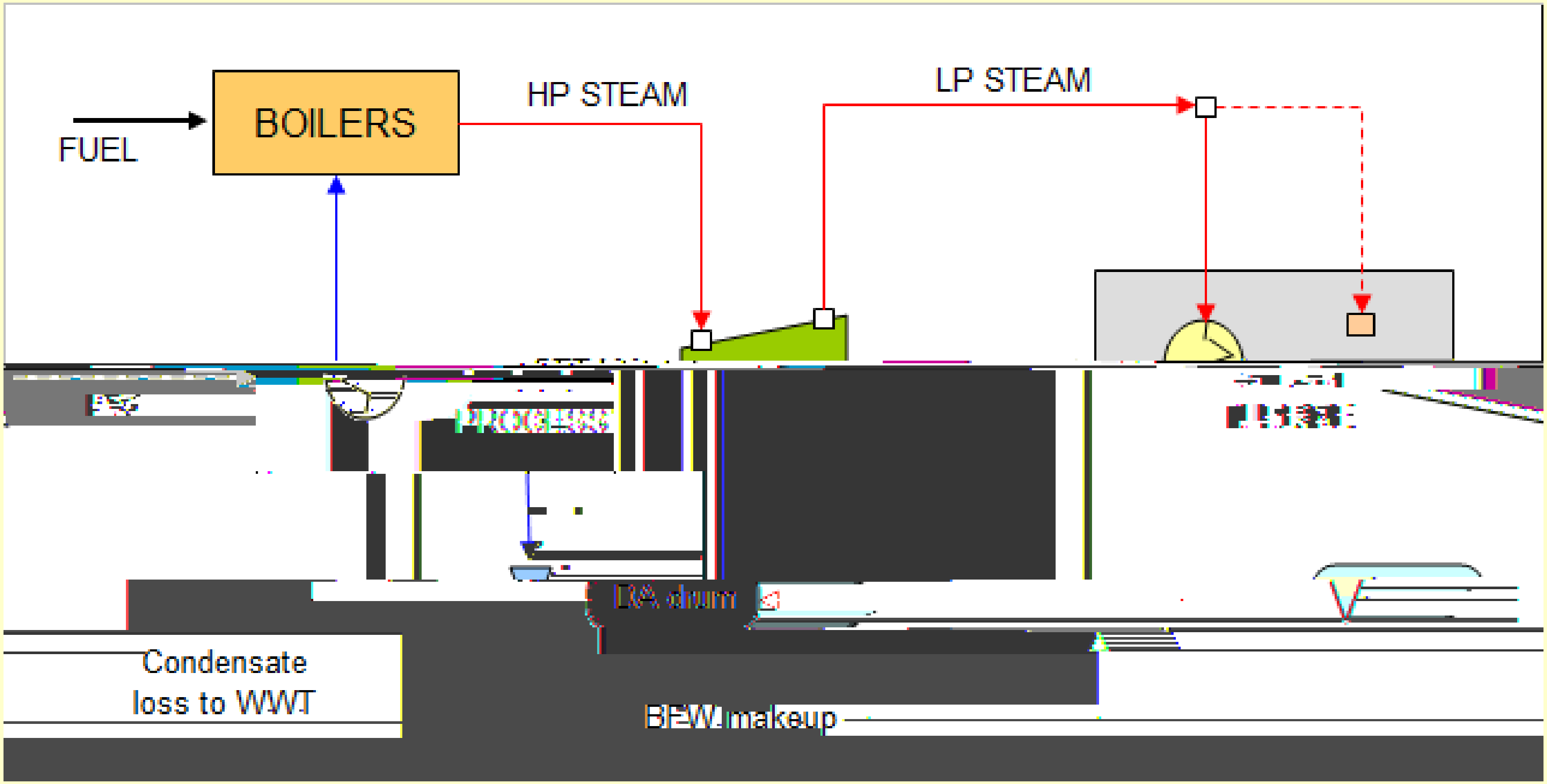
Extraction Turbine



Induction Turbine

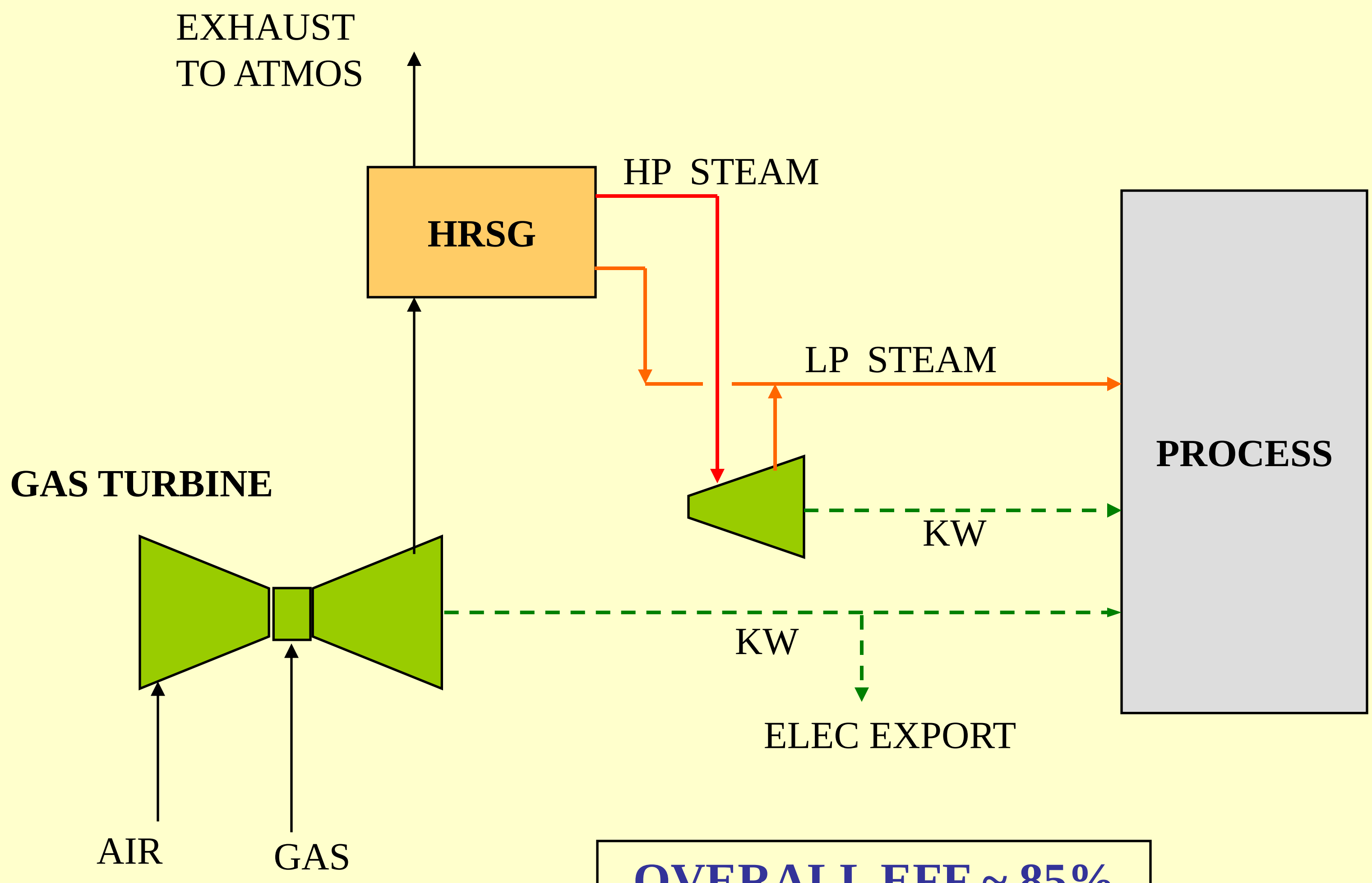
Variations – hybrid Cogen and Condensing

Simple Rankine Cycle flowsheet



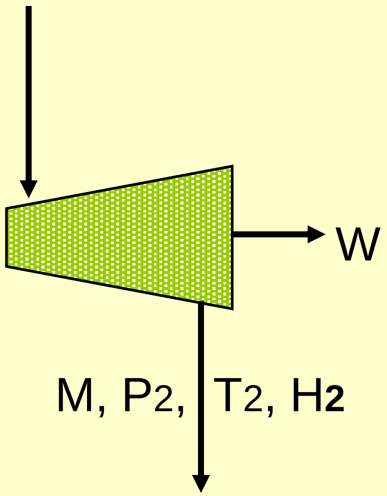
Schematic shown is for cogeneration mode

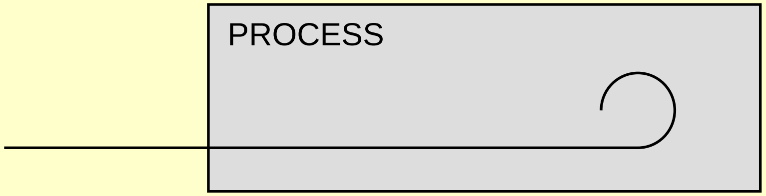
The ultimate Combined-cycle Cogen scheme



OVERALL EFF ~ 85%

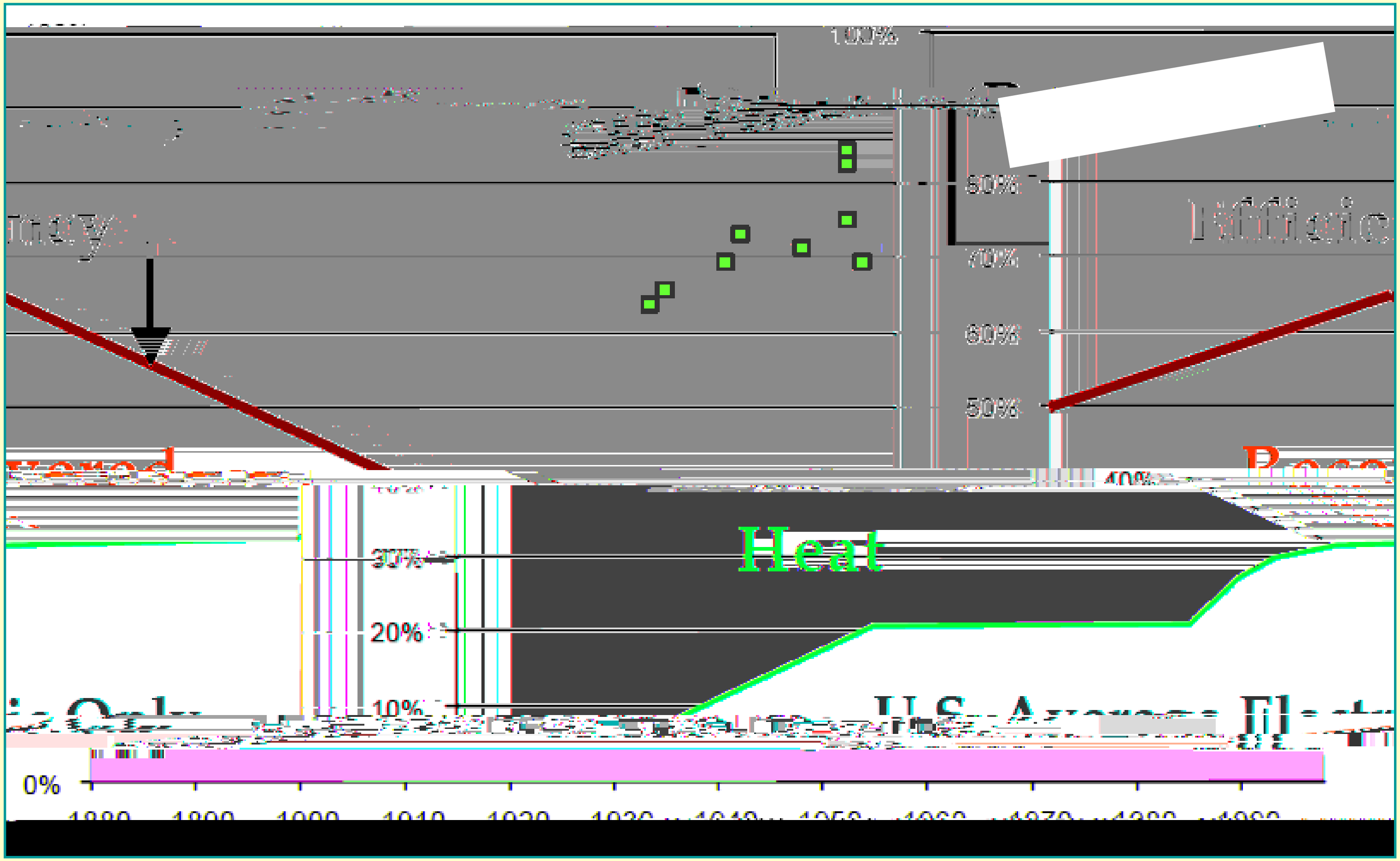
Different types of ST Efficiency





- Machine Efficiency = $W/Q_{in} = (H_1\text{-}H_2)/H_1$
- Isentropic Efficiency $= W/[M.(H_1 – H_2)_{max}]$ $= (H_1\text{-}H_2)/(H_1\text{-}H'_2)$
- System efficiency

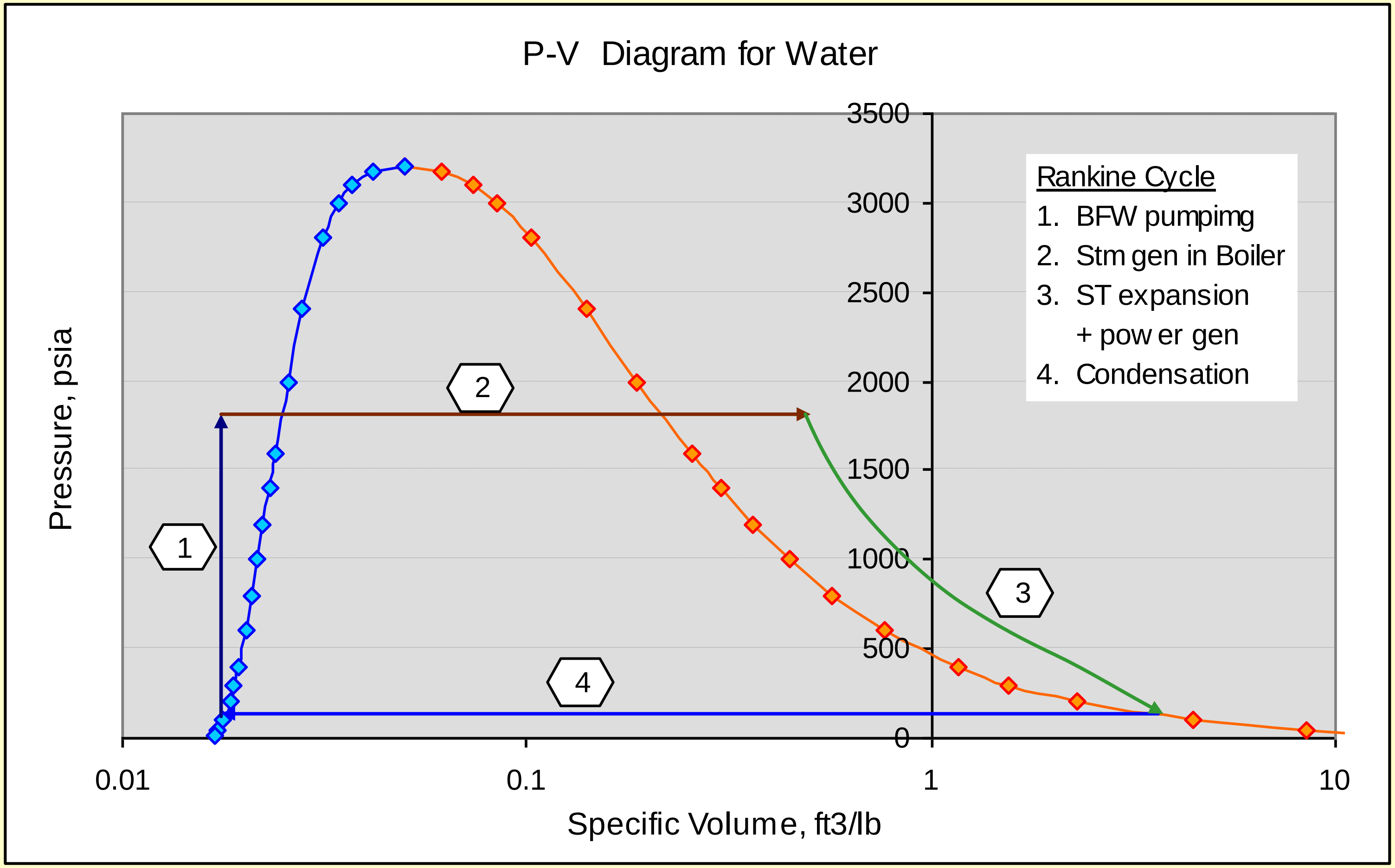
A Bit of History …



US Power plants stopped cogenerating ~1960

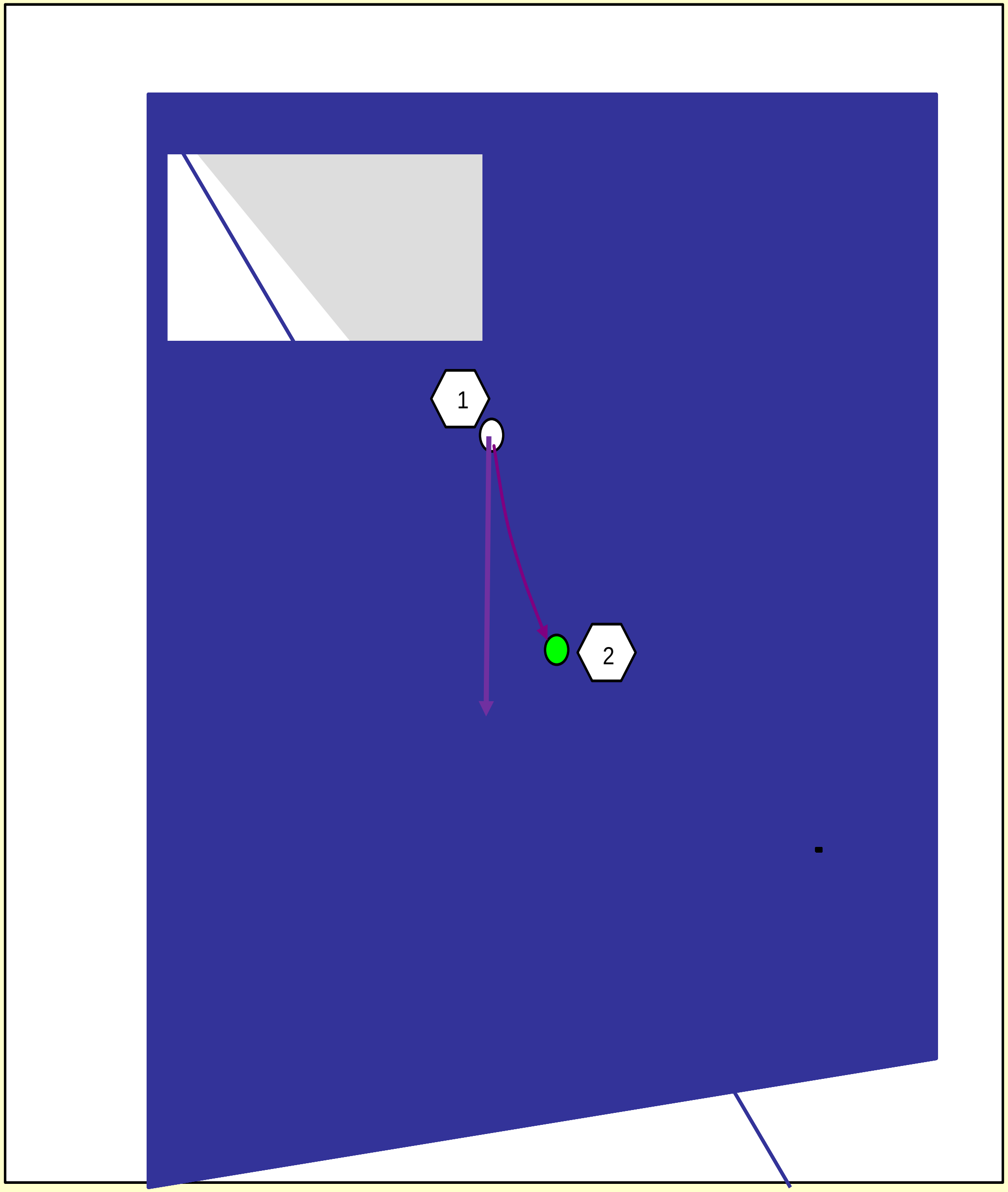
THERMODYNAMICS REVIEW

Rankine cycle on the P-V diagram



Power generation step (#3) on Mollier Chart

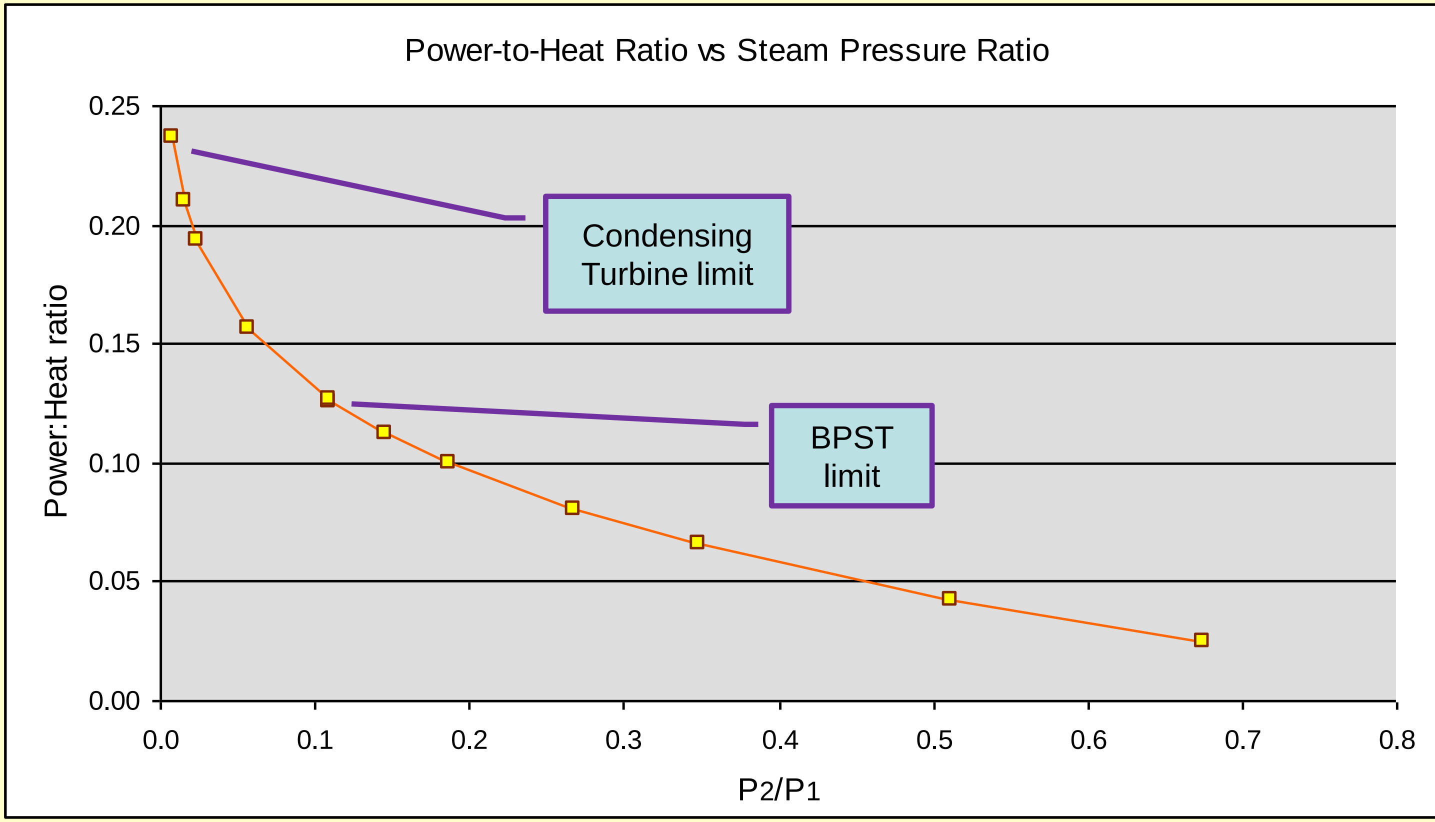
- Adiabatic expansion
  (from 600 psig, 700ºF to 50 psig)
- Isentropic efficiency



Effect of P_2/P_1 on Machine Efficiency (W/Q_{in})

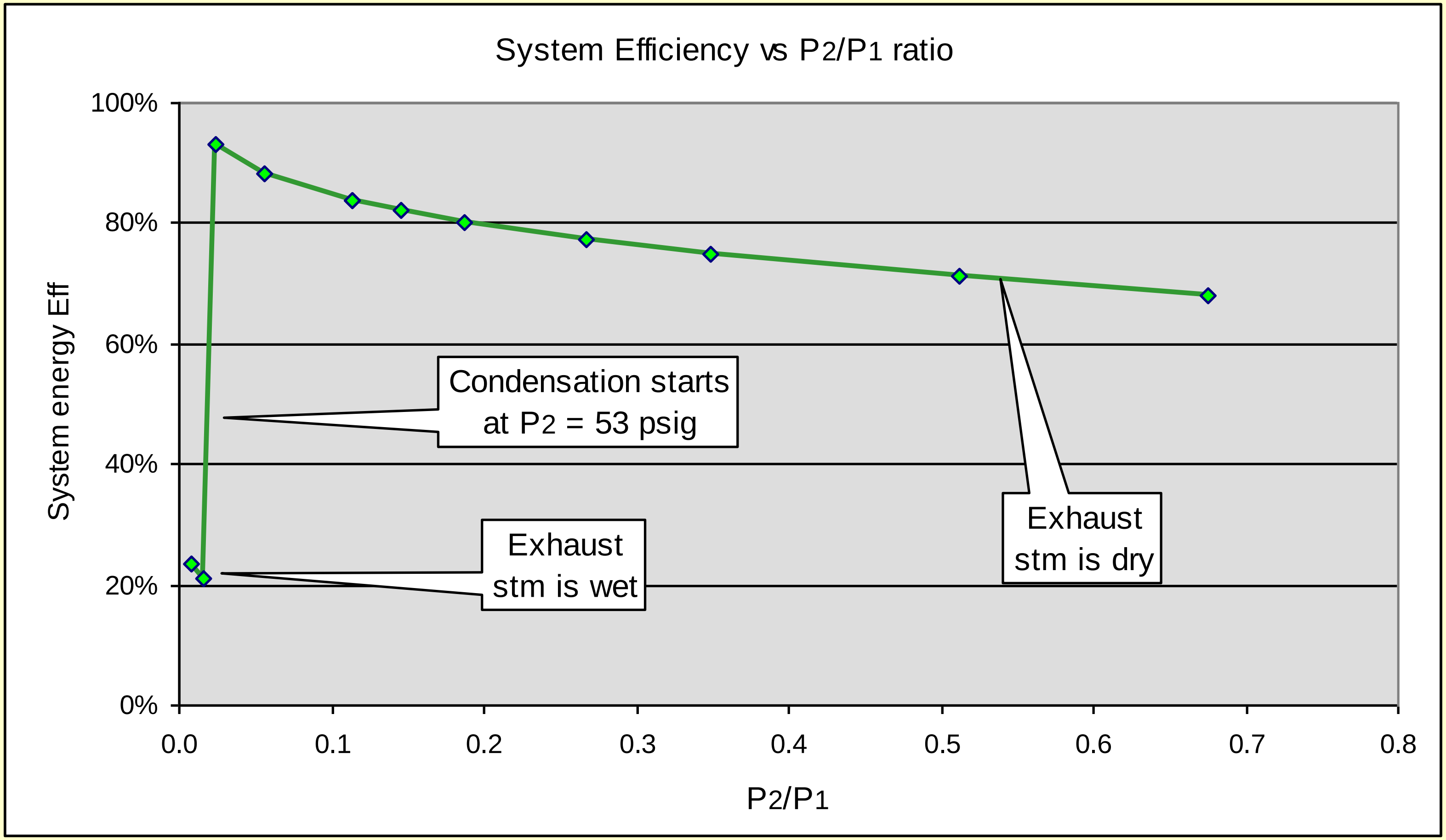
Near-optimal Inlet Conditions for industrial cogen systems

Inlet steam	
flow, lb/h	100,000
psig	600
psia	614.7
sat T	489
[illegible]	[illegible]



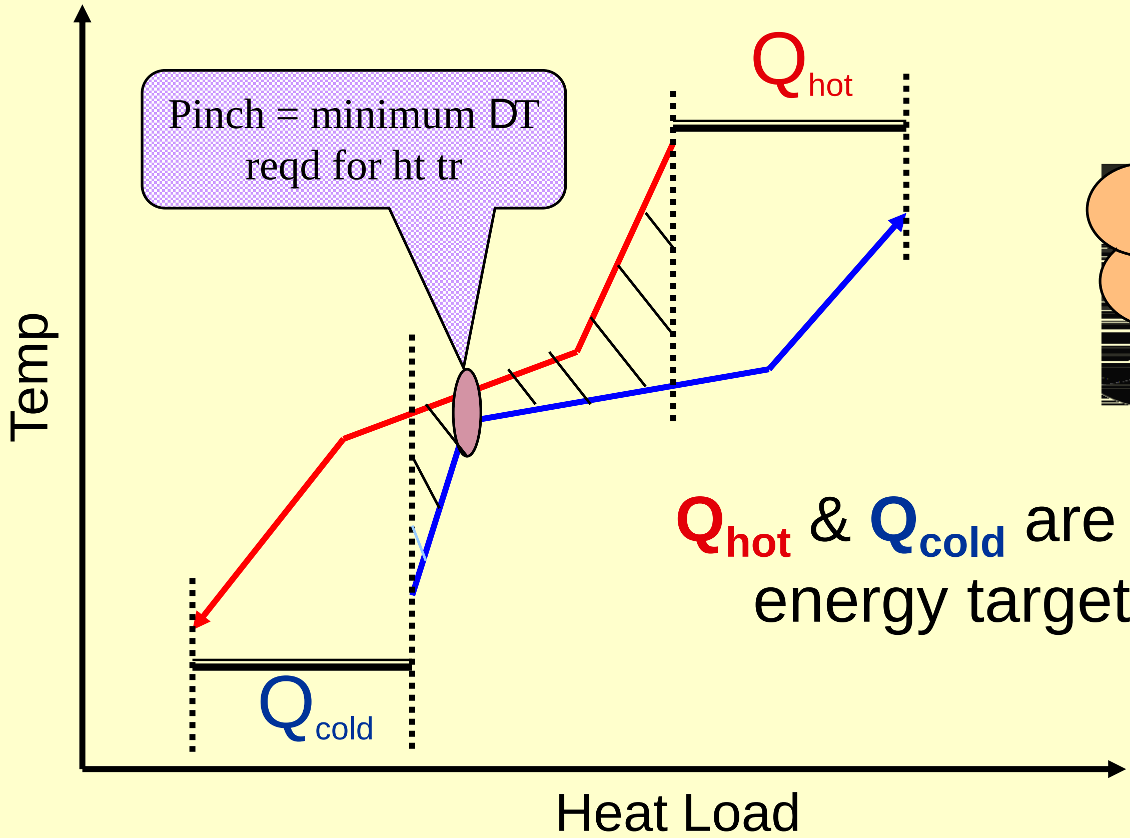
Theoretical Machine Efficiency tops out at ~13% for BPST and 24% for CST before moisture content in turbine reaches dangerous levels.

Effect of P_2/P_1 on System Efficiency



System Efficiency peaks when exhaust steam is saturated, drops rapidly as P_2/P_1 is falls, slowly as P_2/P_1 rises

OPTIMUM TURBINE INTEGRATION



Q_{hot} & Q_{cold} are the energy targets

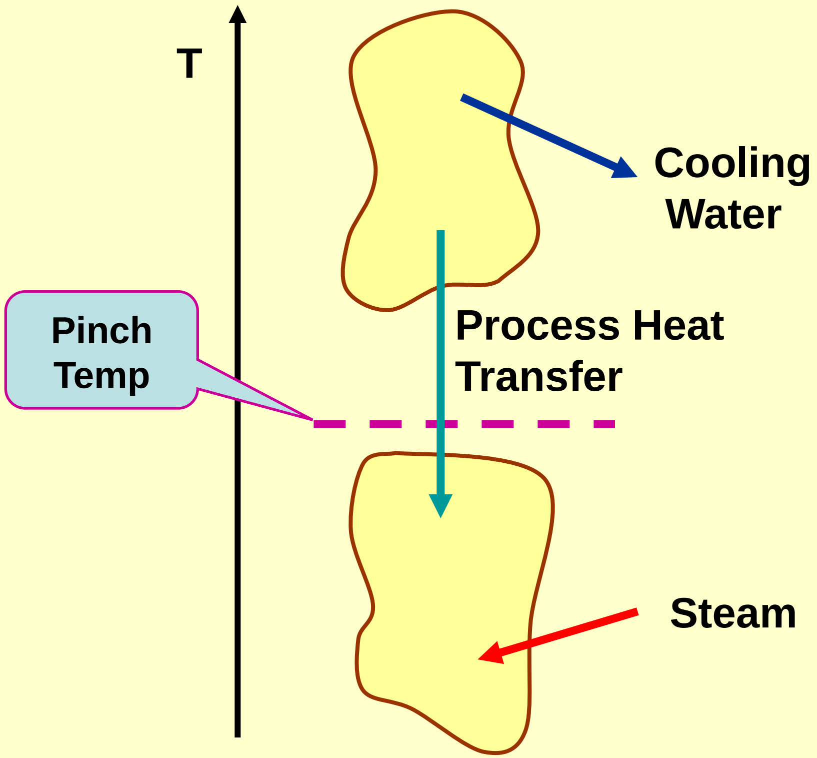
It is possible to consolidate ALL the heating and cooling duties in the process into two **Composite Curves** that show the enthalpy change requirements between the entire temperature range over which the process operates

The Pinch Principle - 1

Q

If we allow **XP** heat transfer, Q_h and Q_c both increase by **XP**

The Pinch Principle - 2



To achieve the Energy Targets, **<u>DO NOT</u>**

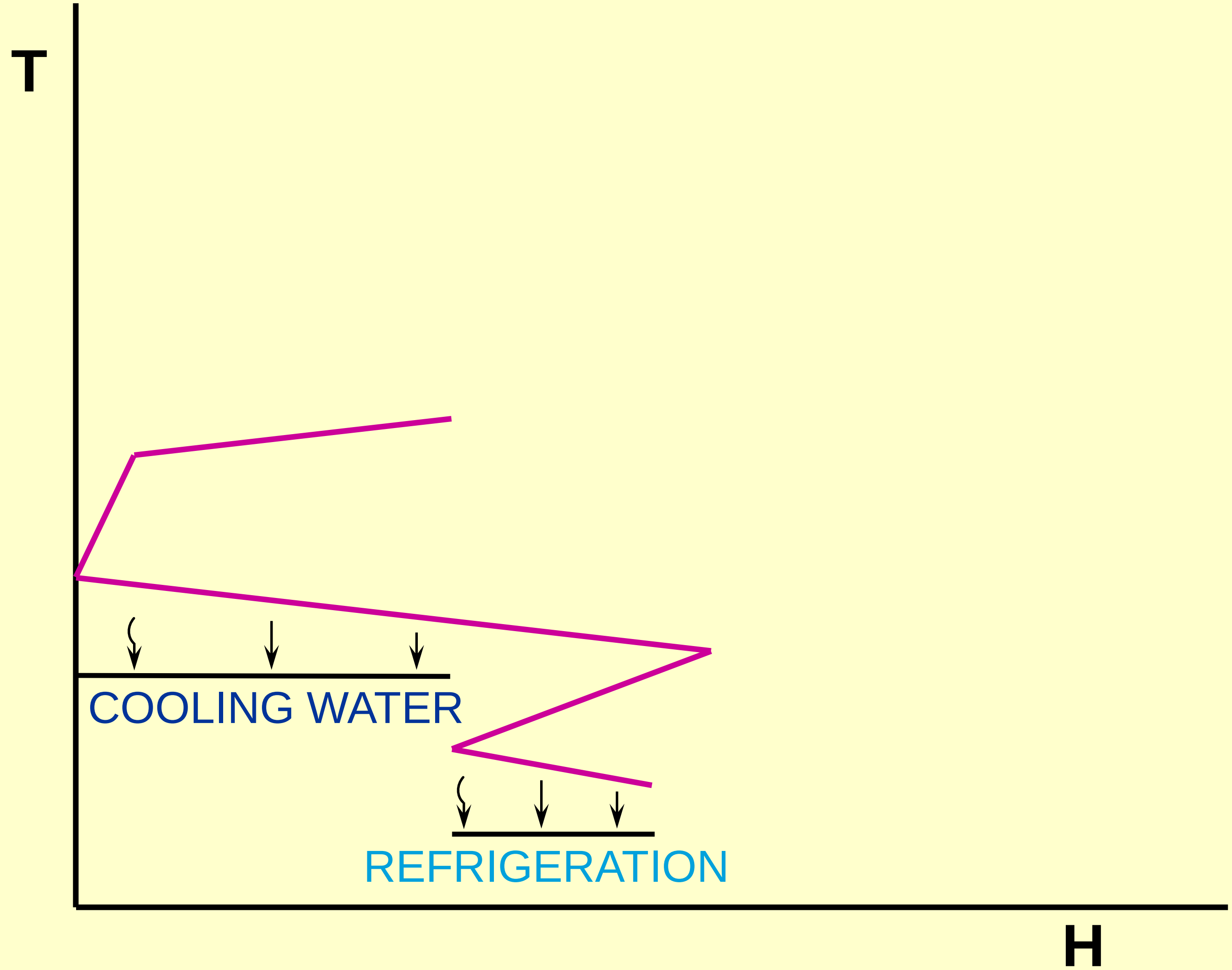
- use Steam below Pinch
- use CW above Pinch
- transfer heat from process streams above Pinch to process streams below Pinch

Summary of Energy Balances

Parameter	Integrate Across PP	Integrate Above PP	Integrate Below PP
Process steam from fired boiler	A	A	A
Turbine steam from fired boiler	Q	Q	0
Turbine steam from WHB below Pinch	0	0	Q
Turbine exhaust vapor	Q – W	Q – W	Q – W
Net HP steam required	A + Q	A+W	A
Net Total Cooling Duty	B + (Q-W)	B	B – W
[illegible]	[illegible]	[illegible]	[illegible]

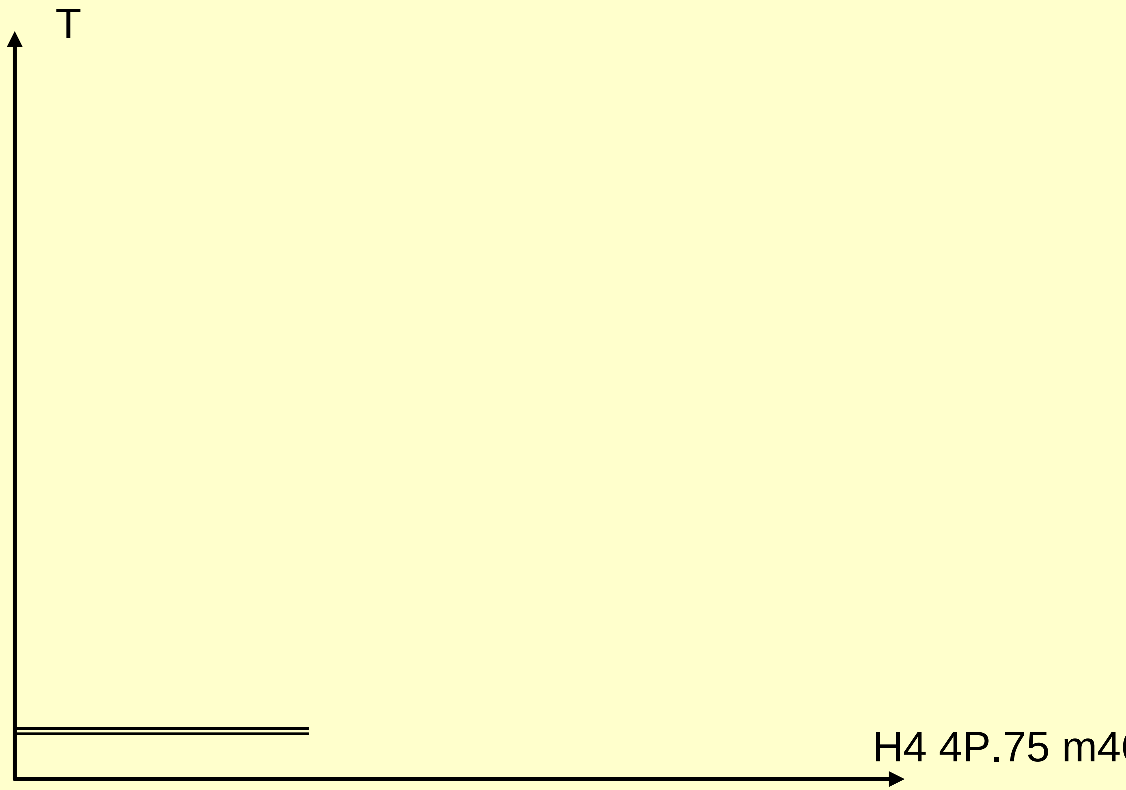
= Machine efficiency

Grand Composite Curve - GCC



Correct Integration of Steam Turbine

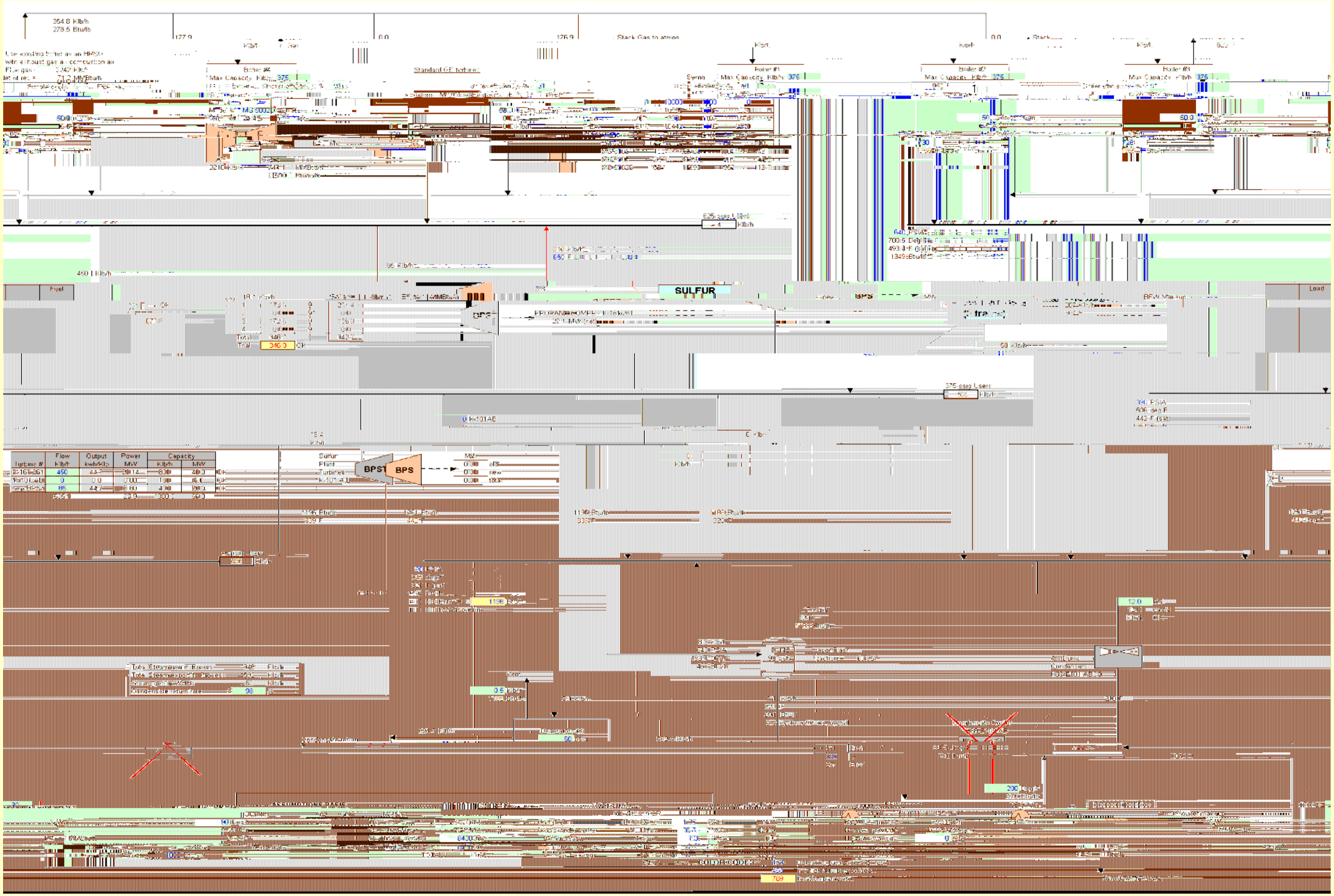
- GCC shows us exactly how much HP and LP steam is needed, and the right P/T levels
- ST must <u>always</u> exhaust ABOVE the Process Pinch
- When designed this way, payback is very good, typically 3-4 yrs



Total Site Source-Sink curves

Net process
cooling demand
= available heat

CHP SIMULATION MODELS



Excellent Tool for Analysis

Model should include all Key System Features:

- Multiple steam levels
- Multiple boilers (with eff. curves)
- Process WHBs
- Steam and Gas turbines (incl HRSG)
- PRVs, Desuperheaters
- Condensate recovery (by steam pr level)
- Boiler blowdown flash & HX
- Deaerators (could be > 1)
- “Dump condens] נ T] נ T ,dif= ns s Á

Expected Benefits and Costs

- Typical savings = 3-5% of baseline (operator-optimized) energy costs
- Typical installed cost = $500-900K
- Typical Payback << 1 yr
- Proven in dozens of Oil refineries, Chemical plants, Pulp/Paper mills (can be deemed a Best Practice)

Optimum Process Integration

It's like a jig-saw puzzle, but well worth the effort