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Heat Recovery Steam Generators for Flexibility

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IAGT October 2016

Overview

- The grids needs flexible power
- HRSG and OTSG Designs
- Supplementary Firing
- Fresh Air Firing Case Study
- Balance of Plant Considerations

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The Grid Needs Flexible Power

Changes in Electricity Generation

- Base loaded power plants
  - High fixed costs
  - Low operating costs
    - Nuclear, Coal
  - Large power plants can take days to reach steady state

Source: www.opg.com

Pickering (~3.1GW)

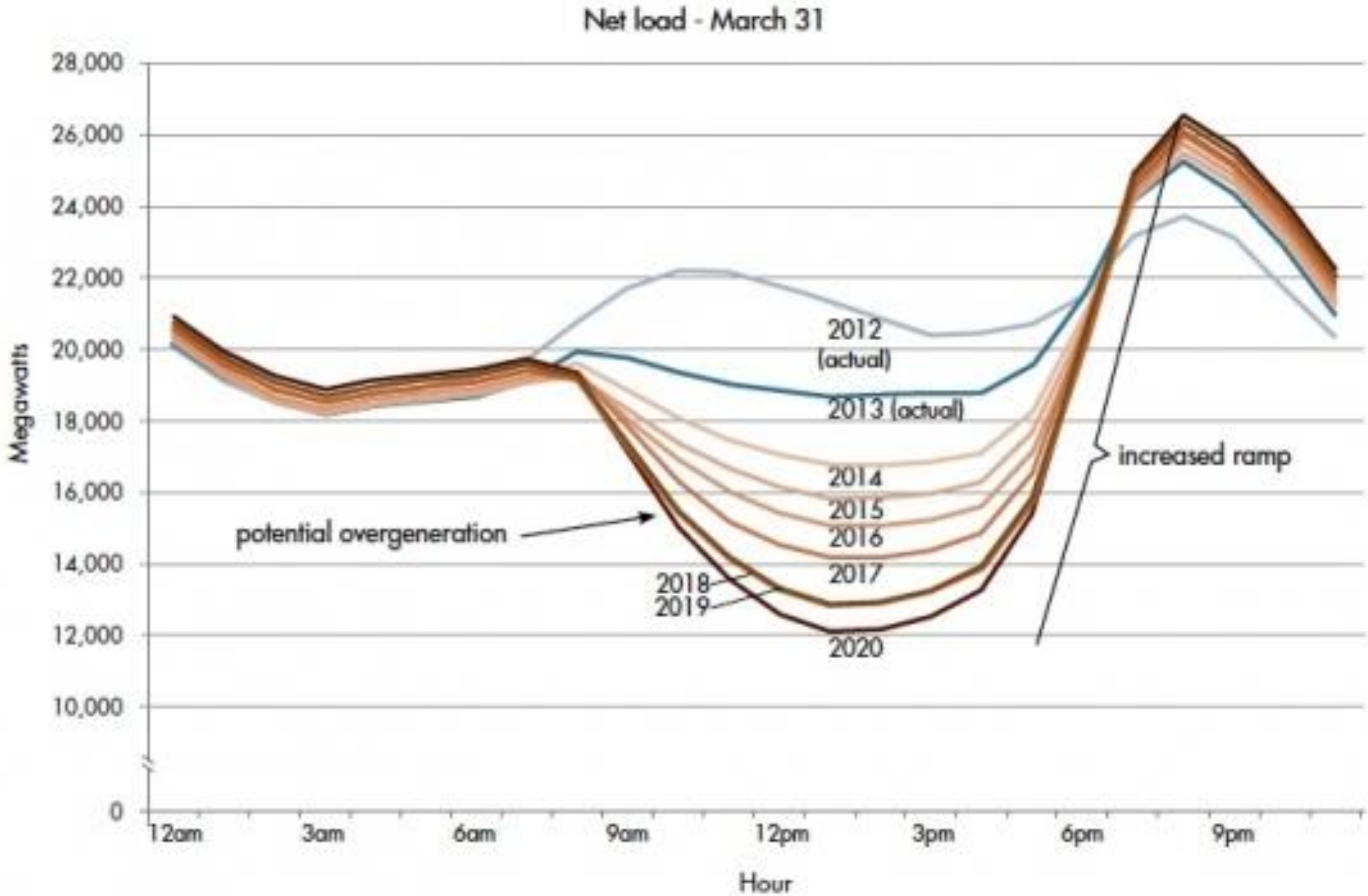
Nanticoke Generating Station (~4GW)

Changes in Electricity Generation

- Peaking Power Plants
  - Simple Cycle Power Plants
  - Combined Cycle Power Plants (CCPPs)
  - Hydroelectric
  - Renewables

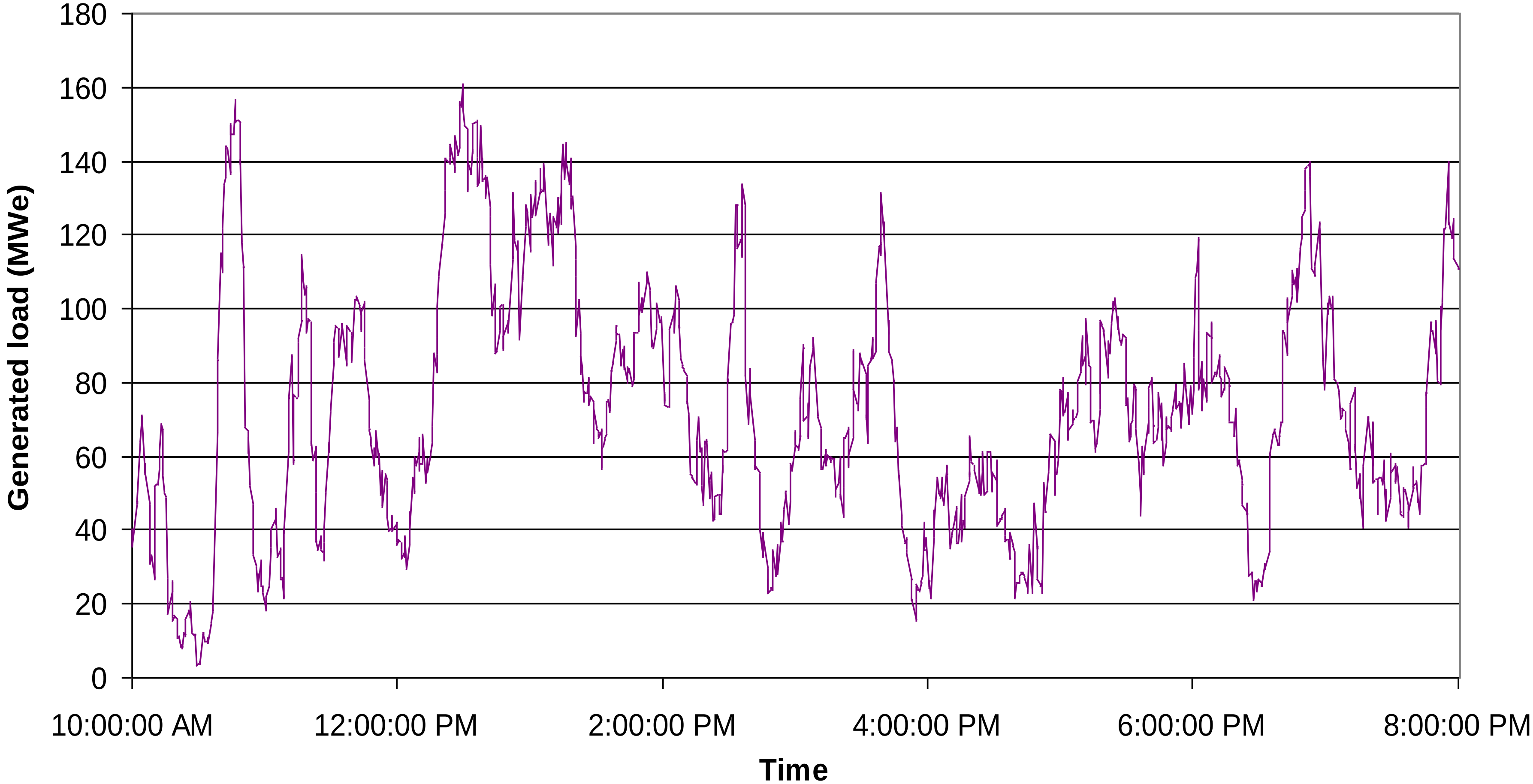
Source: www.opg.com

California's "Duck" Curve



Changes in Electricity Generation

- OTSG-based cycling combined cycle plant loading



Changes in Electricity Generation

- Combined Cycle power plants could be based upon industrial or aeroderivative type turbines
  - Industrial
    - Heavy & rugged
    - Longer start up times
    - Longer maintenance schedule

  Well suited to plants that demand base-loaded efficiency

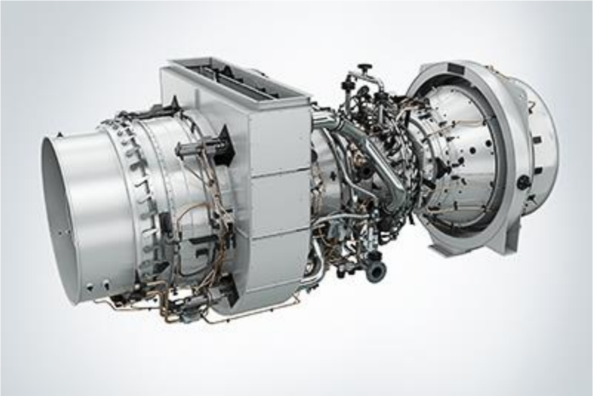
  - Aeroderivative
    - Light
    - Shorter start up times
    - Shorter maintenance schedule

  Well suited to plants that need to start up/ change load quickly

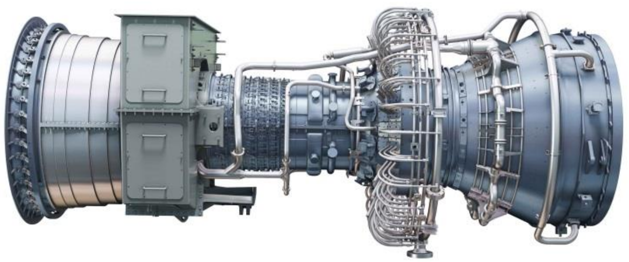
Building a CC with ~50 MW Gas Turbines? Have Fun!

SIEMENS

Aero

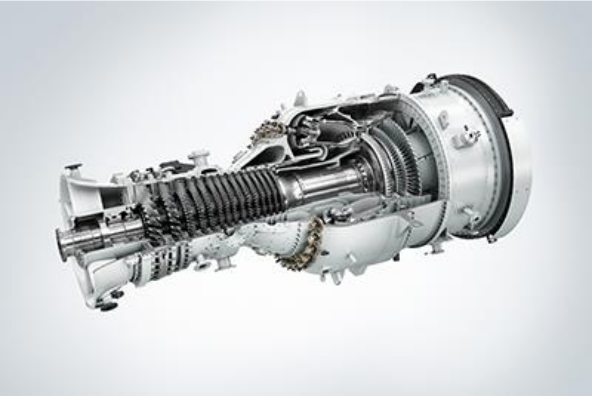


siemens.com



powergen.gepower.com

Frame



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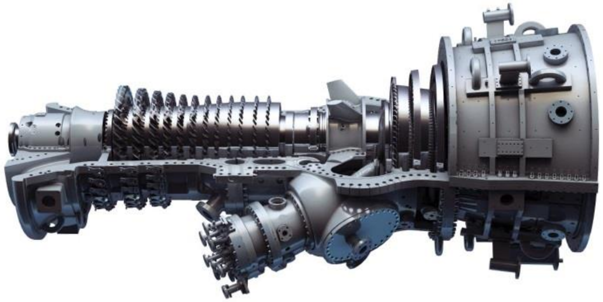

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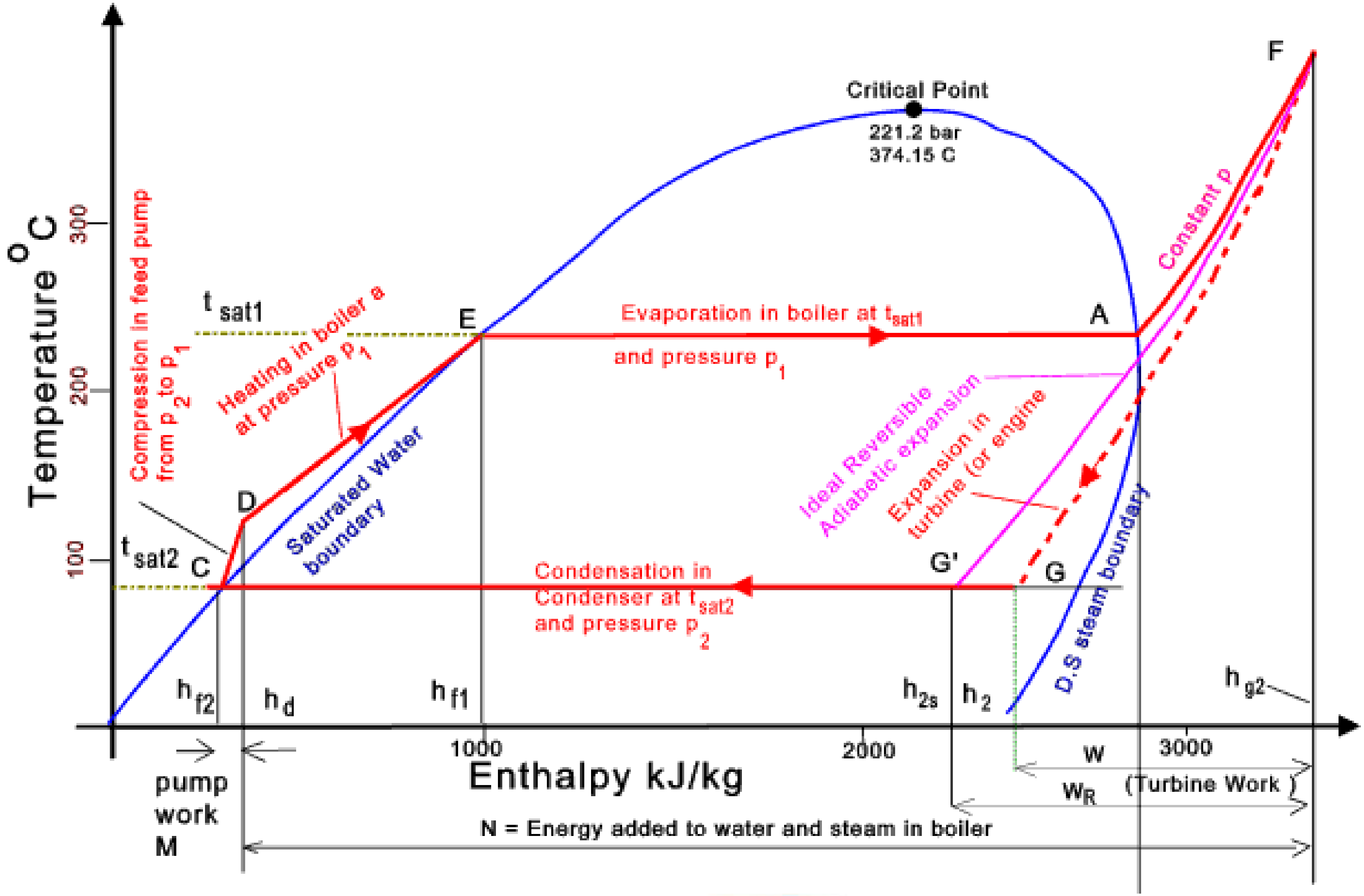
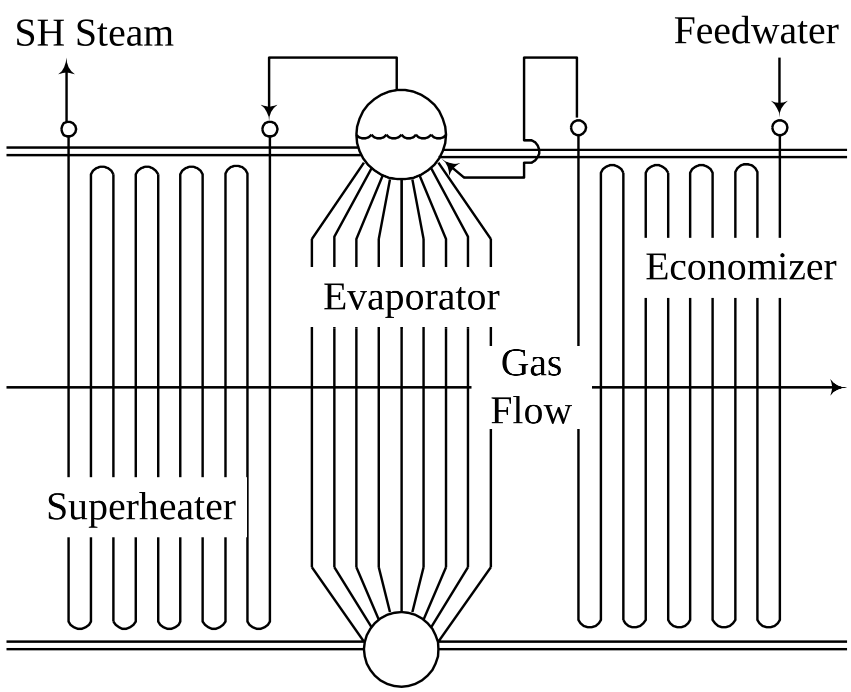
Flexible HRSG Designs

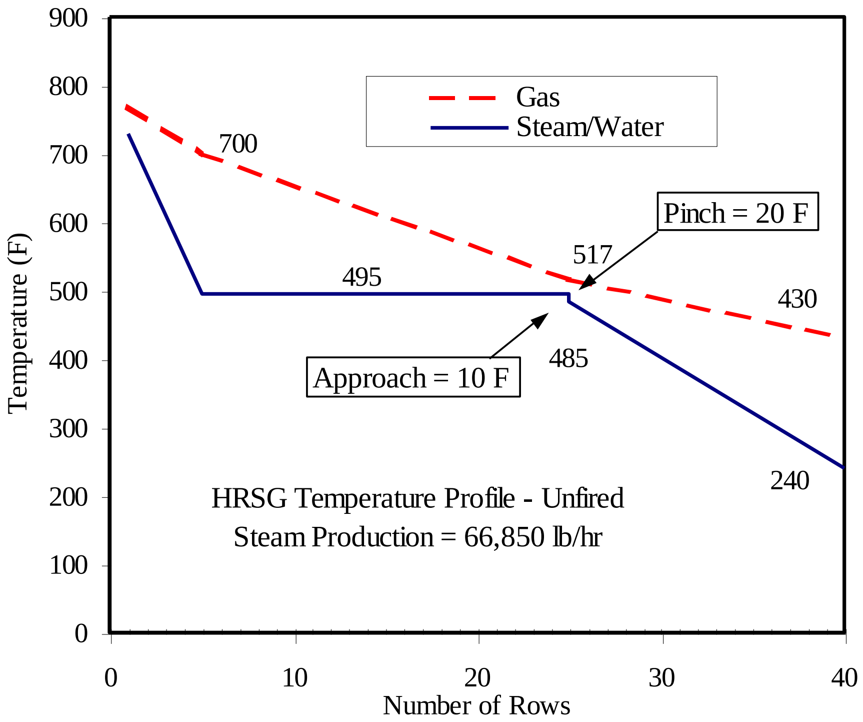
William Rankine Cycle



HRSG Design

- Basic HRSG Design
  - Economizers / Preheaters
  - Evaporators
  - Superheaters / Reheaters





Fundamentals of Transient Response

The laws of the conservation of mass and energy dictate the transient response of steam generators. Simplified equations are provided below.

$W_s - S_d = d/dt\,(W_{in})$ ………. (1)
$Q_s - Q_d = d/dt\,(Q_{in})$ ……….. (2)

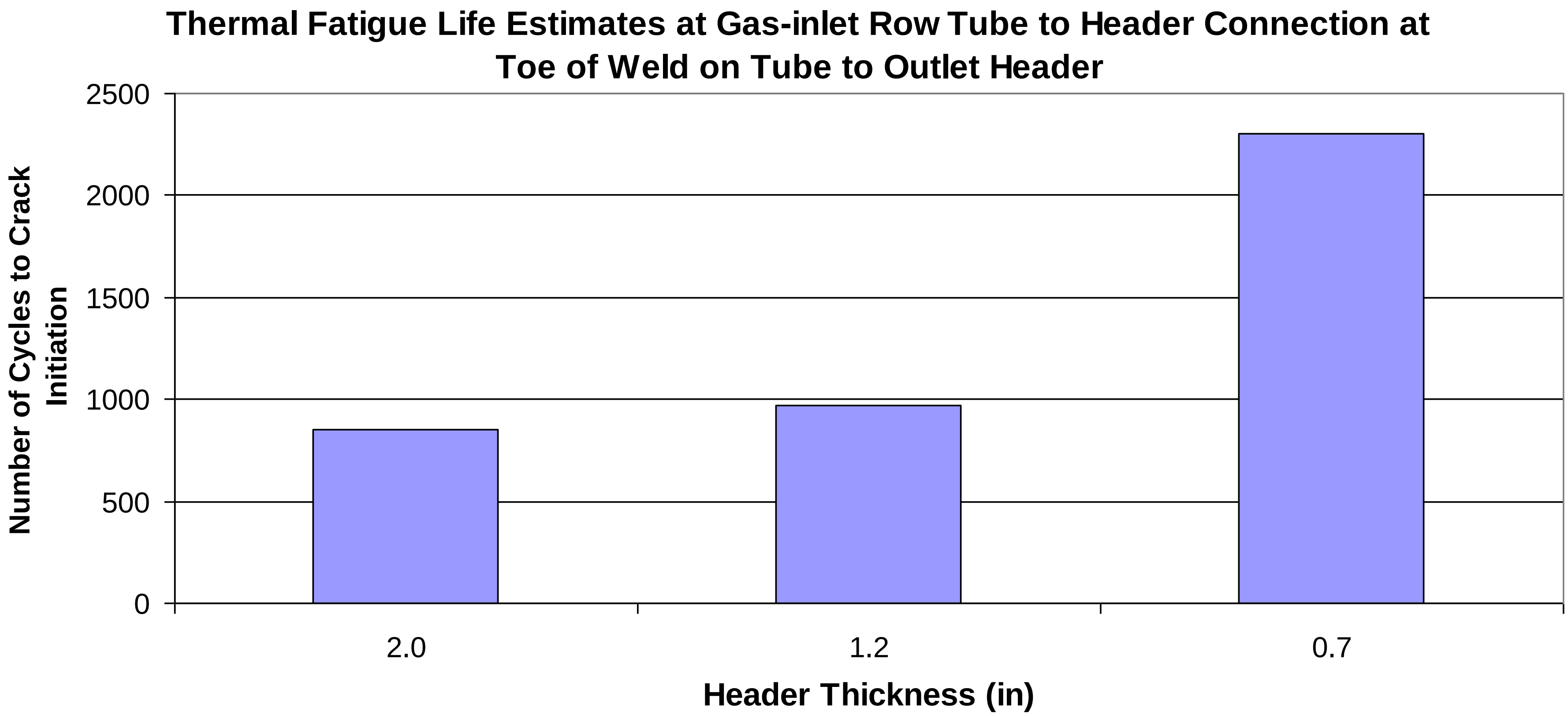
where:
W_s – quantity of water supplied to the steam generator
Q_s - quantity of heat supplied to the steam generator
S_d – quantity of steam delivered from the steam generator
Q_d – quantity of heat delivered from the steam generator
W_{in} – quantity of water in the steam generator
Q_{in} – quantity of heat in the steam generator

$Q_{in} = (M_m c_m t_m + M_w c_w t_w + M_s C_s t_s)$
M - mass
C – specific heat
m – metal
w – water
s – steam

Response time is dependant on the water/steam inventory and quantity of heat in the steam generator.

HRSG Design

- HRSG design limitations for cycling
  - Thick drums/headers lead to large cyclic thermal stress

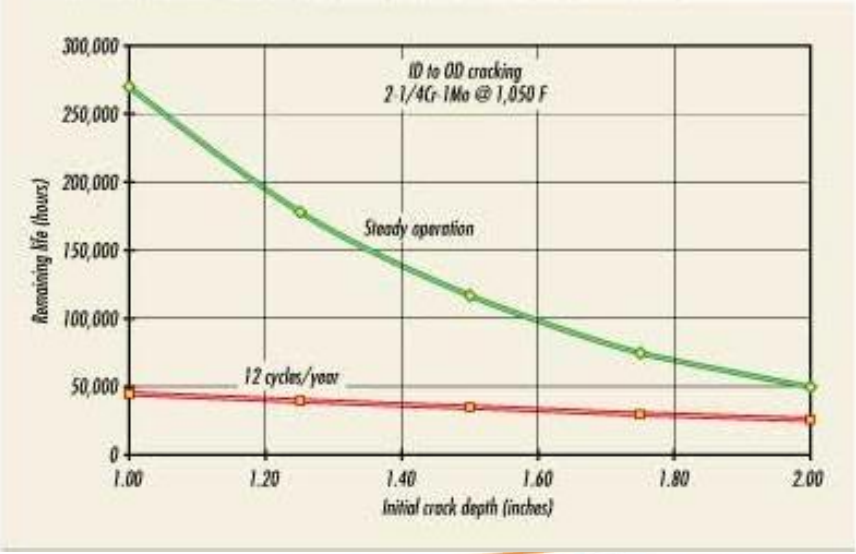


Source: Anderson, R. & Pearson, M., Influences of HRSG and CCGT Design and Operation on the Durability of Two-Shifted HRSGs.

HRSG Design

- HRSG operation drawbacks
  - Superheater drain failures during warm starts
  - Slow start up times
  - There are operational means of maintaining drum heat/pressure during a shutdown to minimize thermal cycling

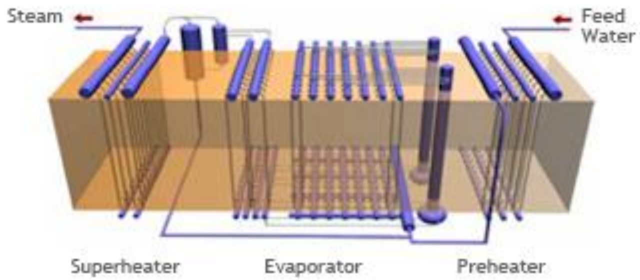
FIGURE 2
IMPACT OF CYCLING ON USEFUL LIFE OF HEADER



Source: Pijper, A., “HRSGs Must Be Designed for Cycling.” Power Engineering, Vol 106, Issue 5.

The Industry's Response

- "The HP drum of our DrumPlus™ requires a small wall thickness and nozzle sizes are minimized. As a result peak stresses are significantly reduced."
- "The startup of a HRSG is limited by the maximum allowable startup saturation temperature rise in the thick HP steam drum (typically in the 2-10° F/minute range)." In reference to the Benson Technology license



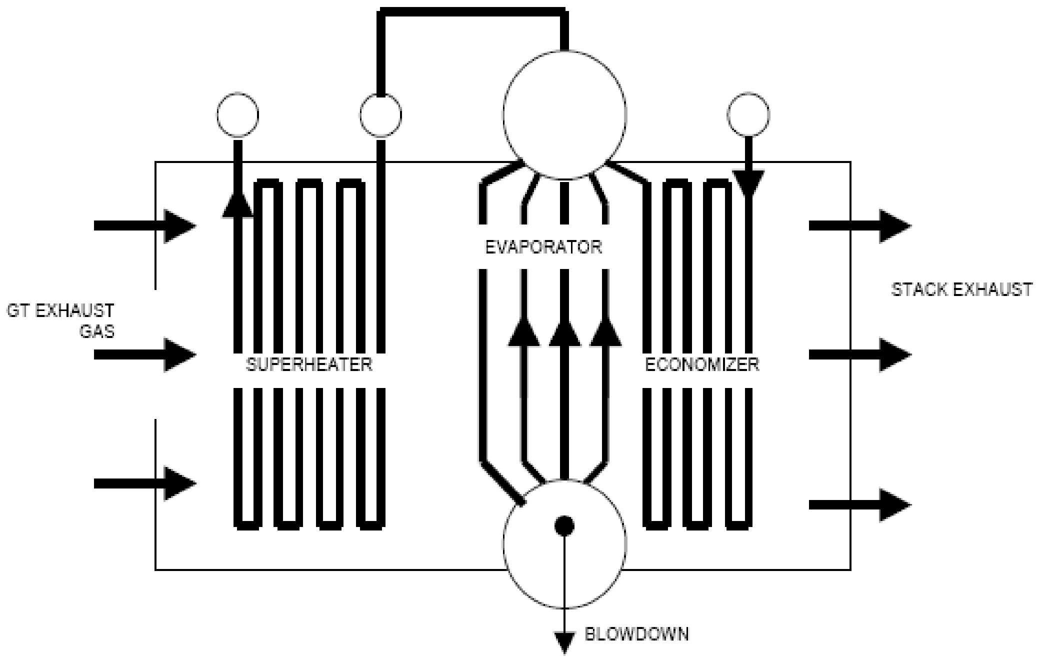
HRSG vs IST OTSG

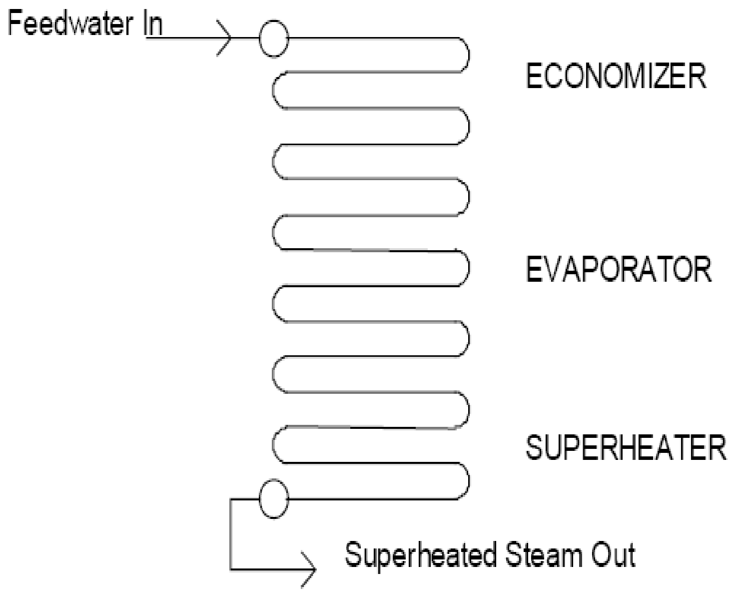
Drum-Type HRSG

Fixed Sections

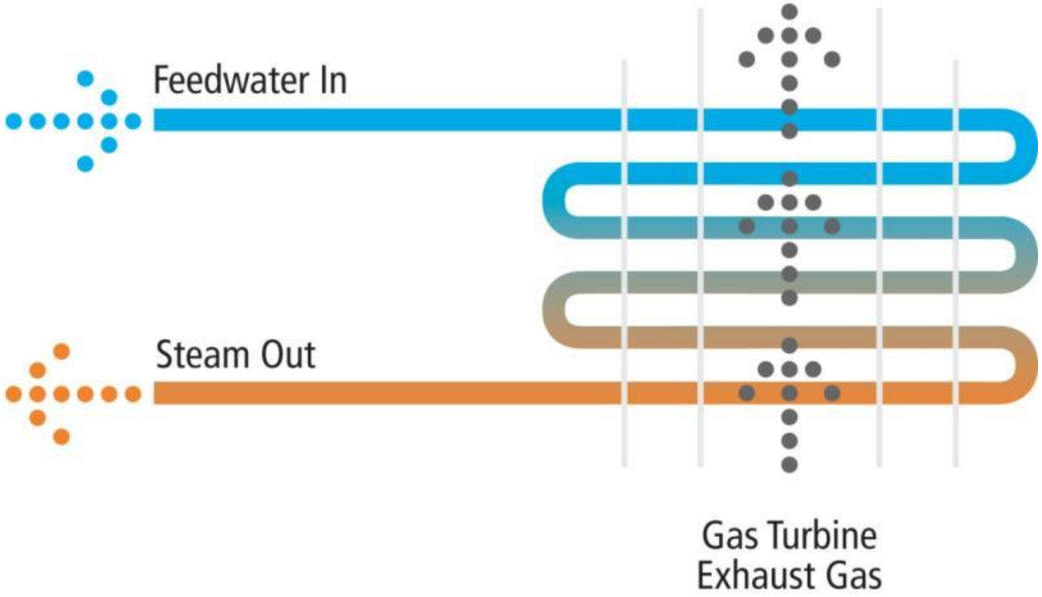
OTSG Type HRSG

Non Fixed Section



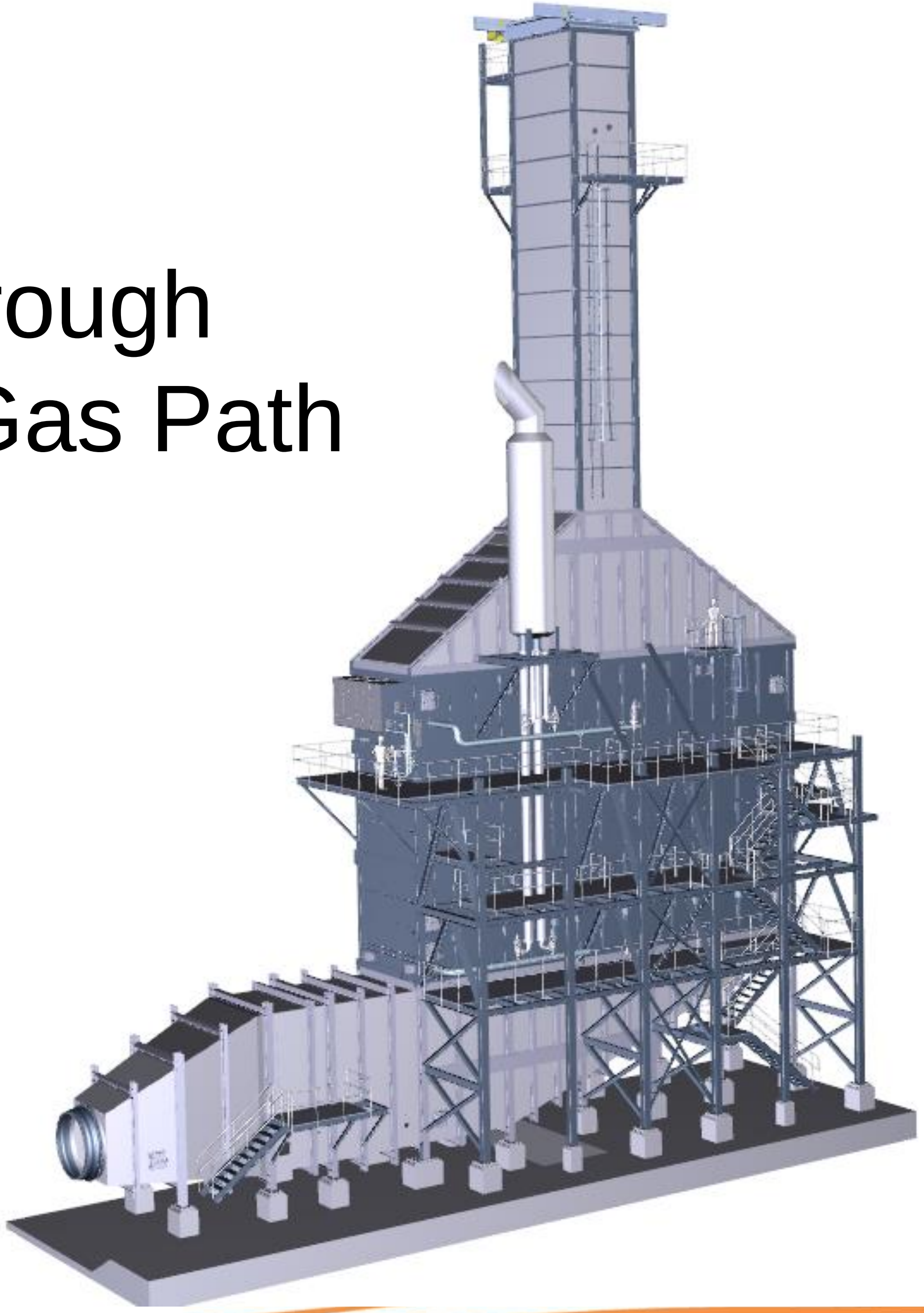


“Drumless” Design



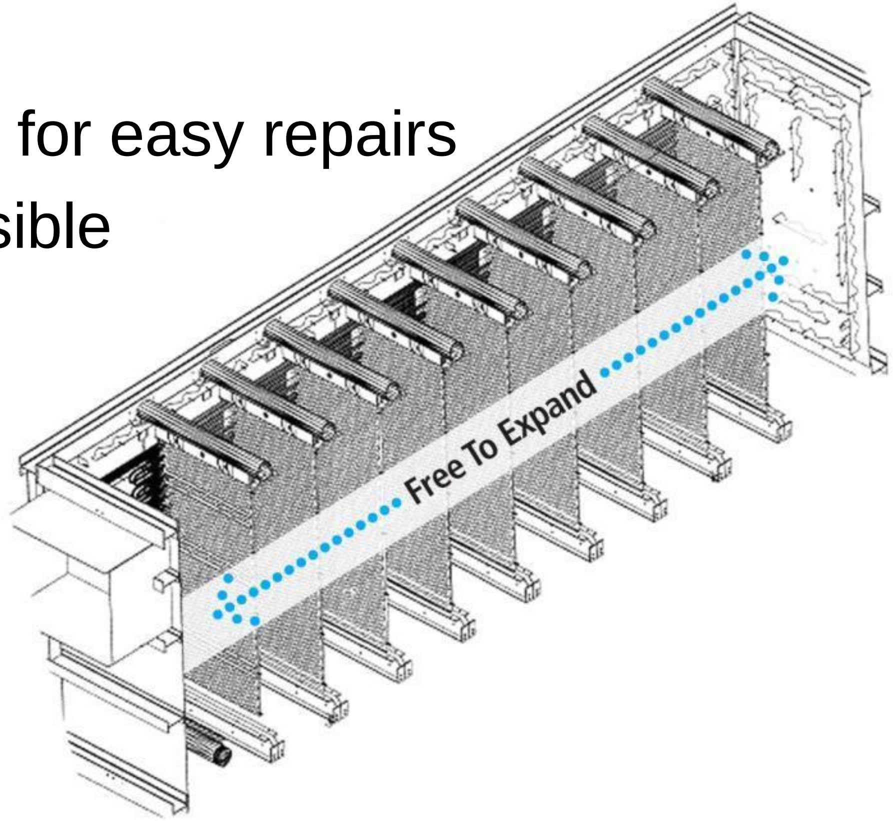
- All tubes thin-walled → low thermal mass → fast cycling
- Compact lightweight pressure bundle
- Simple once through steam path
- Zero Blowdown (no blowdown treatment)

Once Through Vertical Gas Path

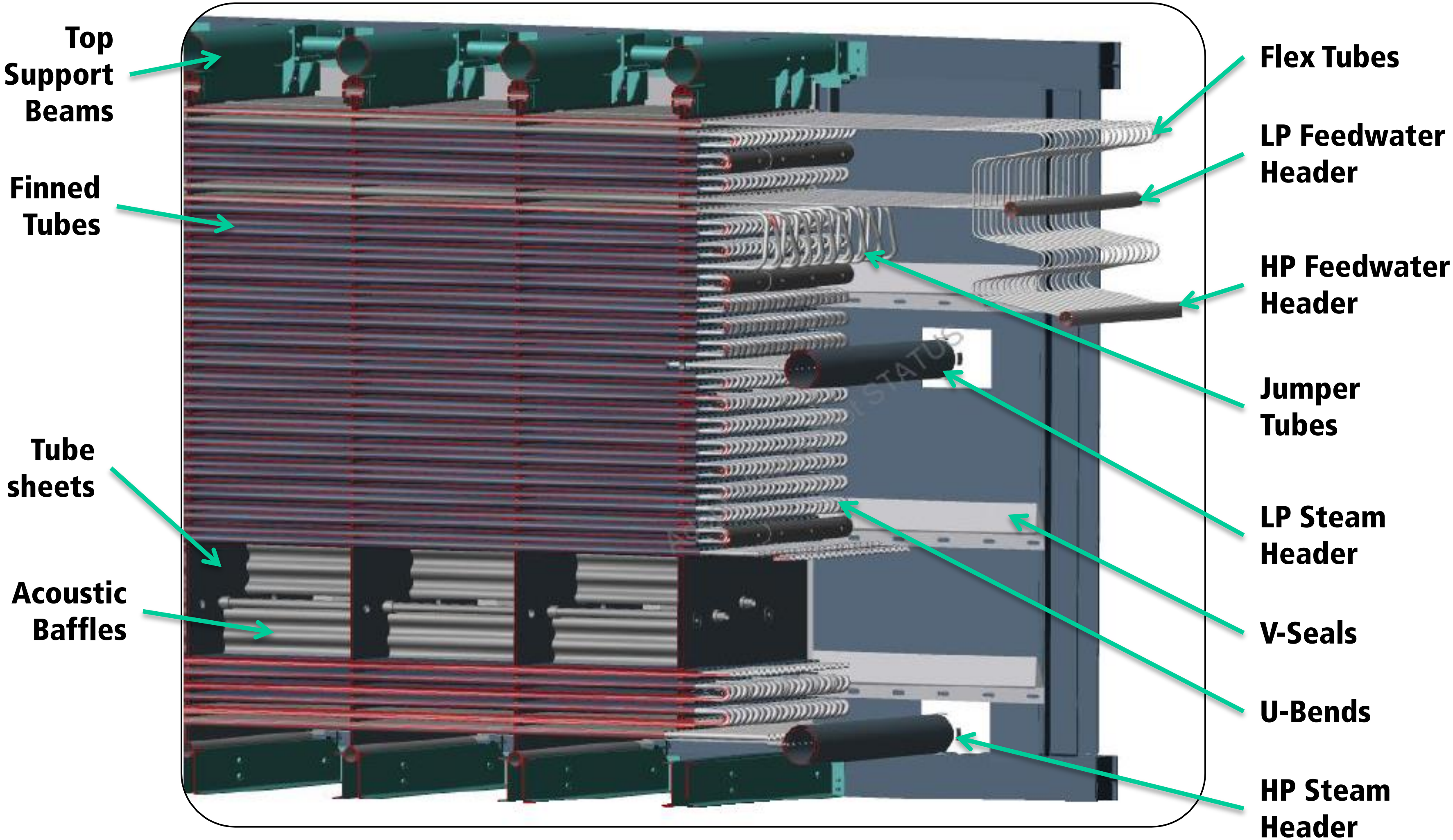


Pressure Module Layout

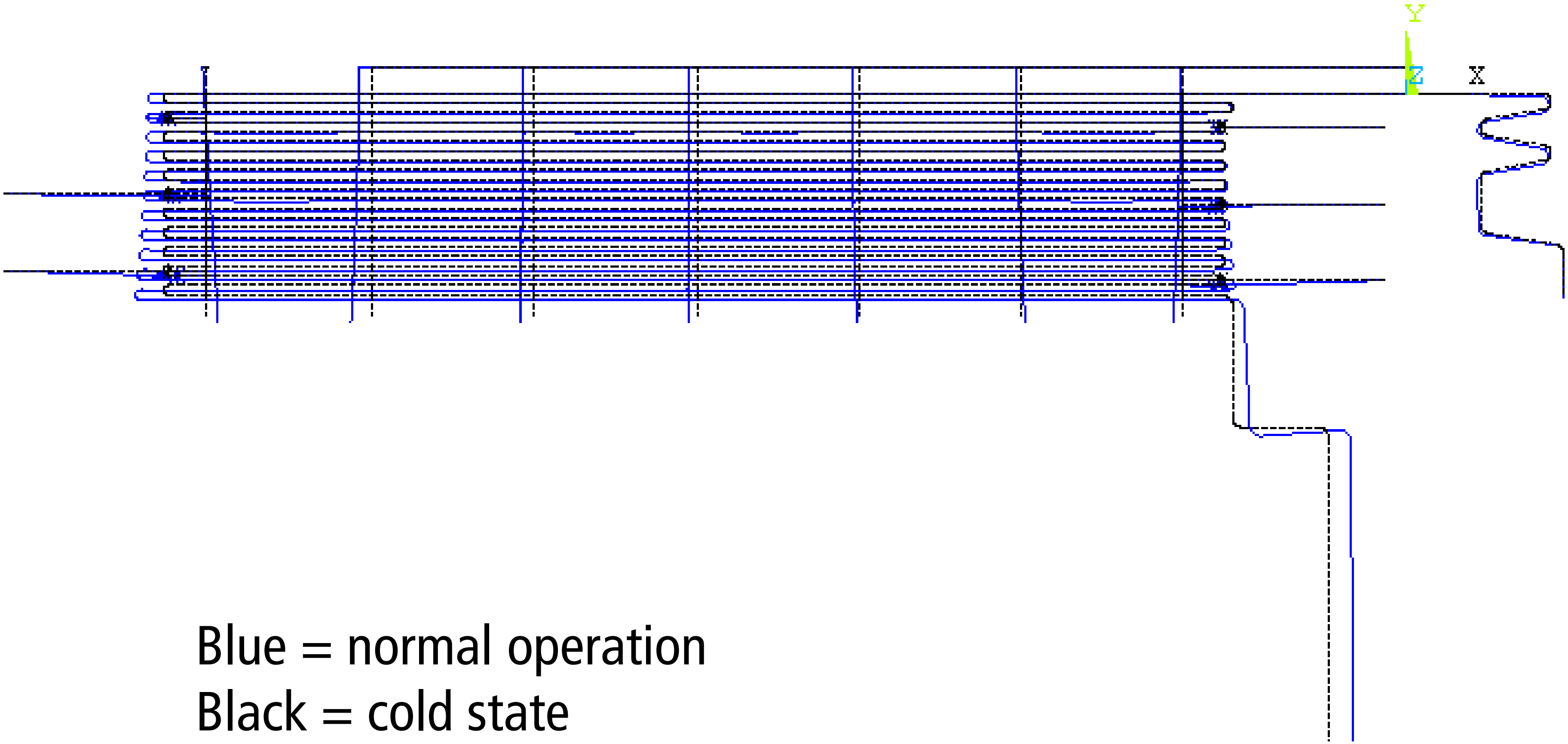
- Tubes held in place by tubesheets
- Entire boiler is designed to freely expand thermally
- Internally insulated casing
- Maintenance cavities allow for easy repairs
- 100% of tube welds accessible



Main Internal Components



OTSG Bundle Movement

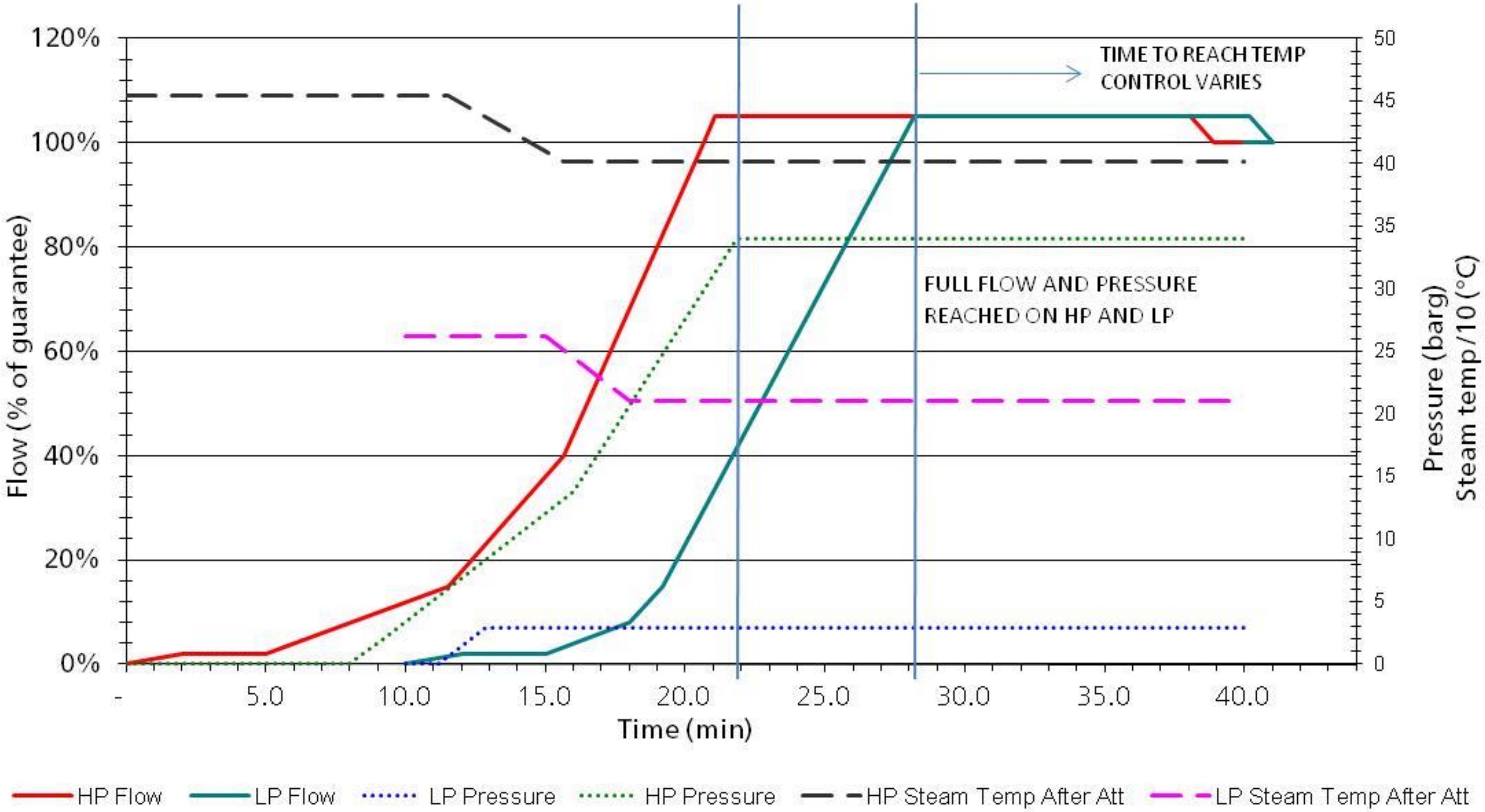


Blue = normal operation
Black = cold state

OTSG Start-Up Curve

(Start Permissive approx 12 min from GT ignition without SCR/CO)

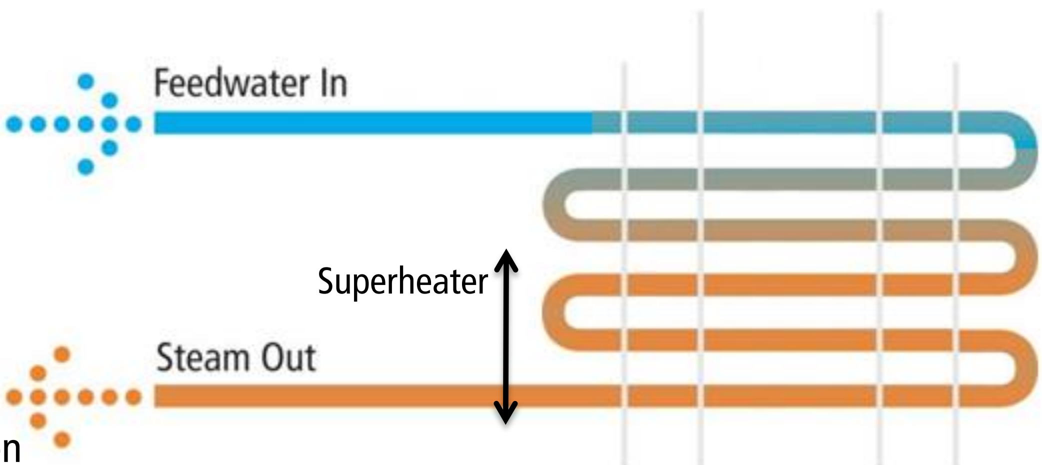
LM6000 (Typical)



Turndown and Flexibility

Normal Operation

- 2+ rows of economizer section
- 1 row of superheated steam



Turndown Operation

- 1-2 rows of economizer section
- 3+ rows of superheated steam

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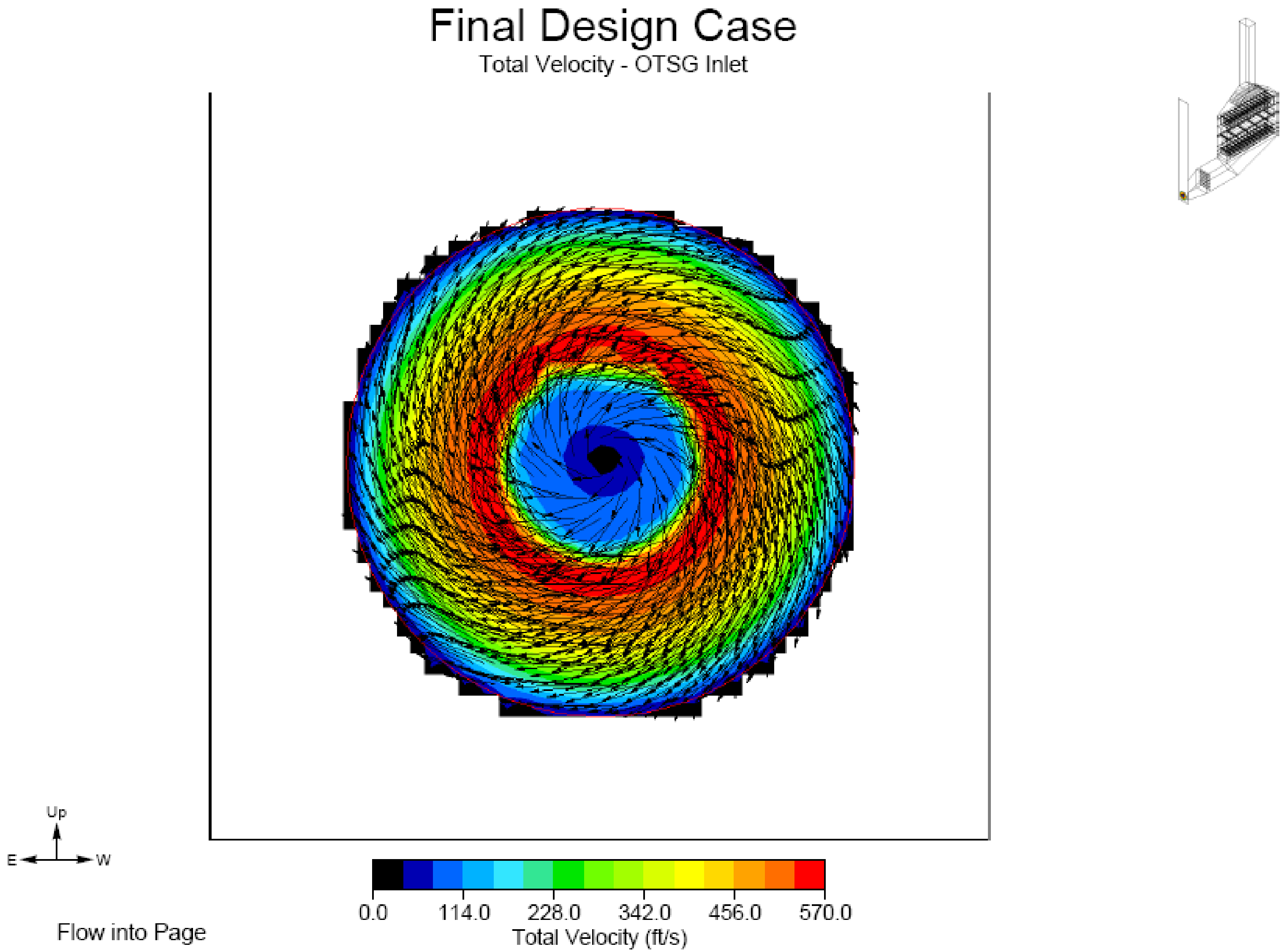
Supplementary Firing

Supplementary Firing

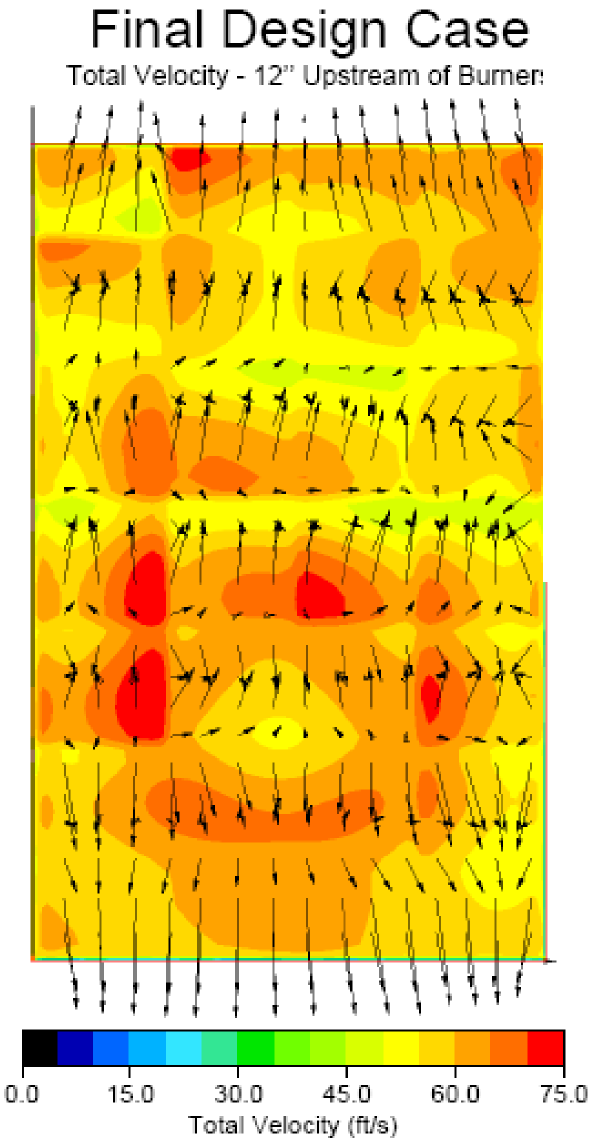
- Combust natural gas (or liquid fuel) in the TEG path to add to the available energy for heat recovery
- Common in cogen applications where the value of the steam exceeds the cost of additional fuel burned
- Natural gas is piped through “runners” and distributed by nozzles across the width of the duct.
- Scope consists of runners, gas distribution manifold, fuel handling skid, and auxiliary blower skid

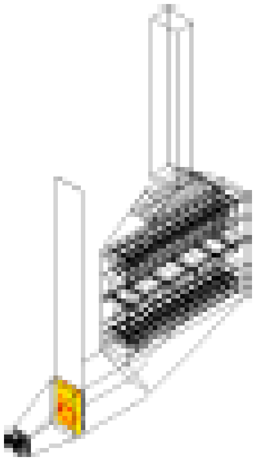
Supplementary Firing – Velocity Distribution



Supplementary Firing – Velocity Distribution

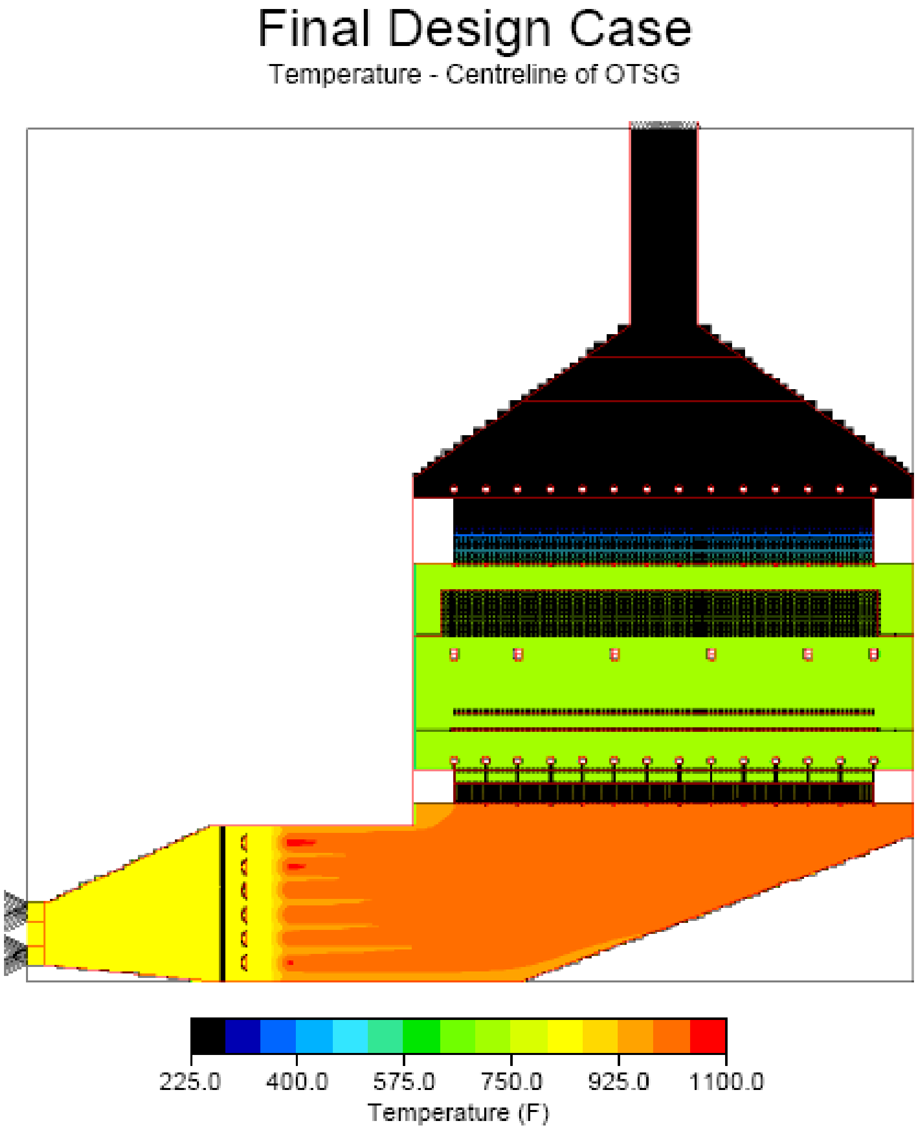
- Distribution Grid + Flow Straightener
  - Flatten velocity profile and remove swirl
- Target 75 ft/s normal operation
  - 35 ft/s minimum
- ±10% of average free stream velocity after distribution grid
- Burner duct length provision
  - 1.5x flame length
- Burner duct liner material
  - 409SS, 304SS, 316SS, Piro Block



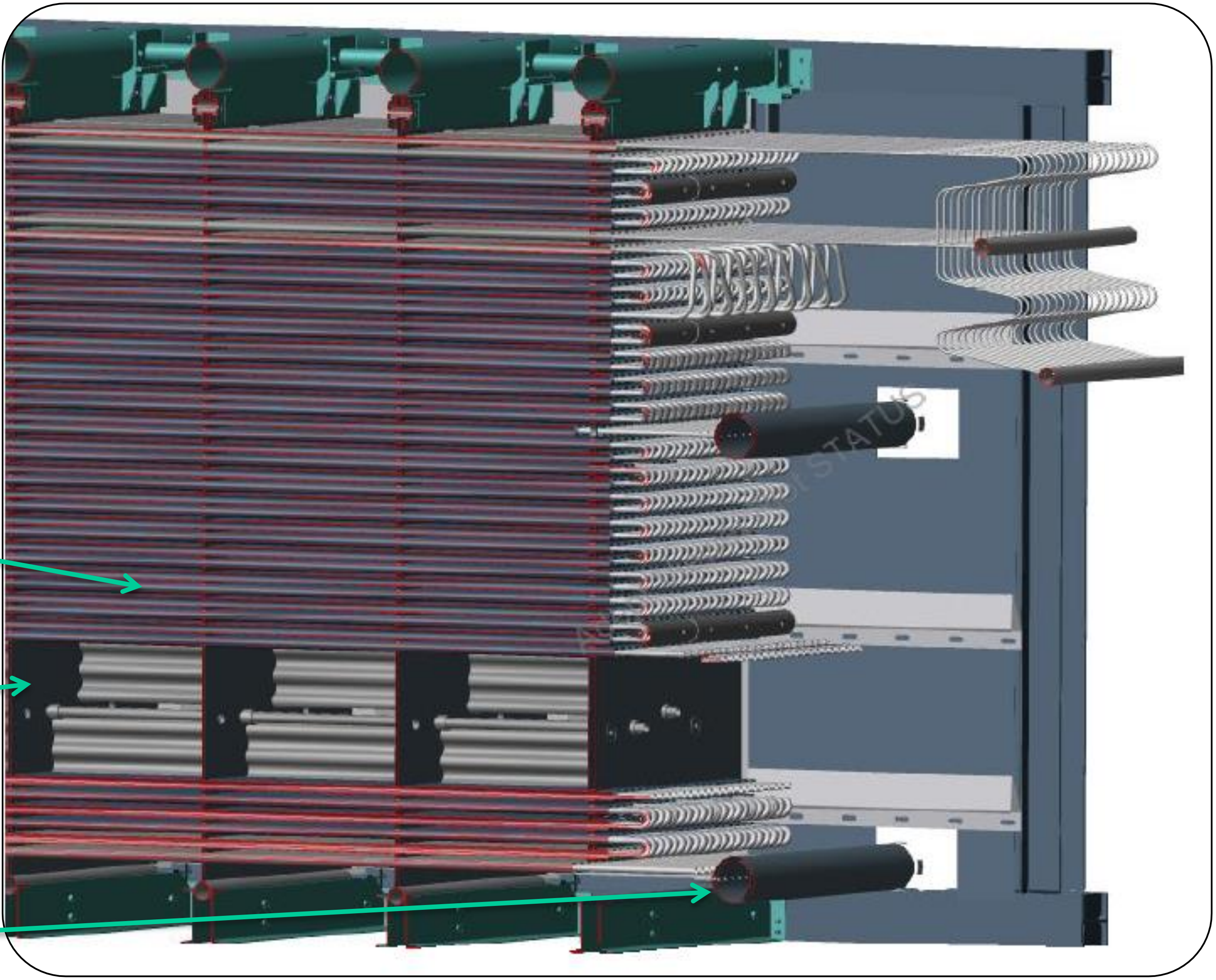


Supplementary Firing – Velocity Distribution

- Typical temperature distribution guarantee +/-10% of the average temperature given a particular velocity profile input guarantee
- Typical heat release from a burner runner is 3 MMBtu/hr per linear foot
  - Increase total heat release by wider duct or more runners (taller duct)
- Duct size is driven by a balance between space required for runners (heat release) and the 75 ft/s target



Module Material Considerations in Fired Applications

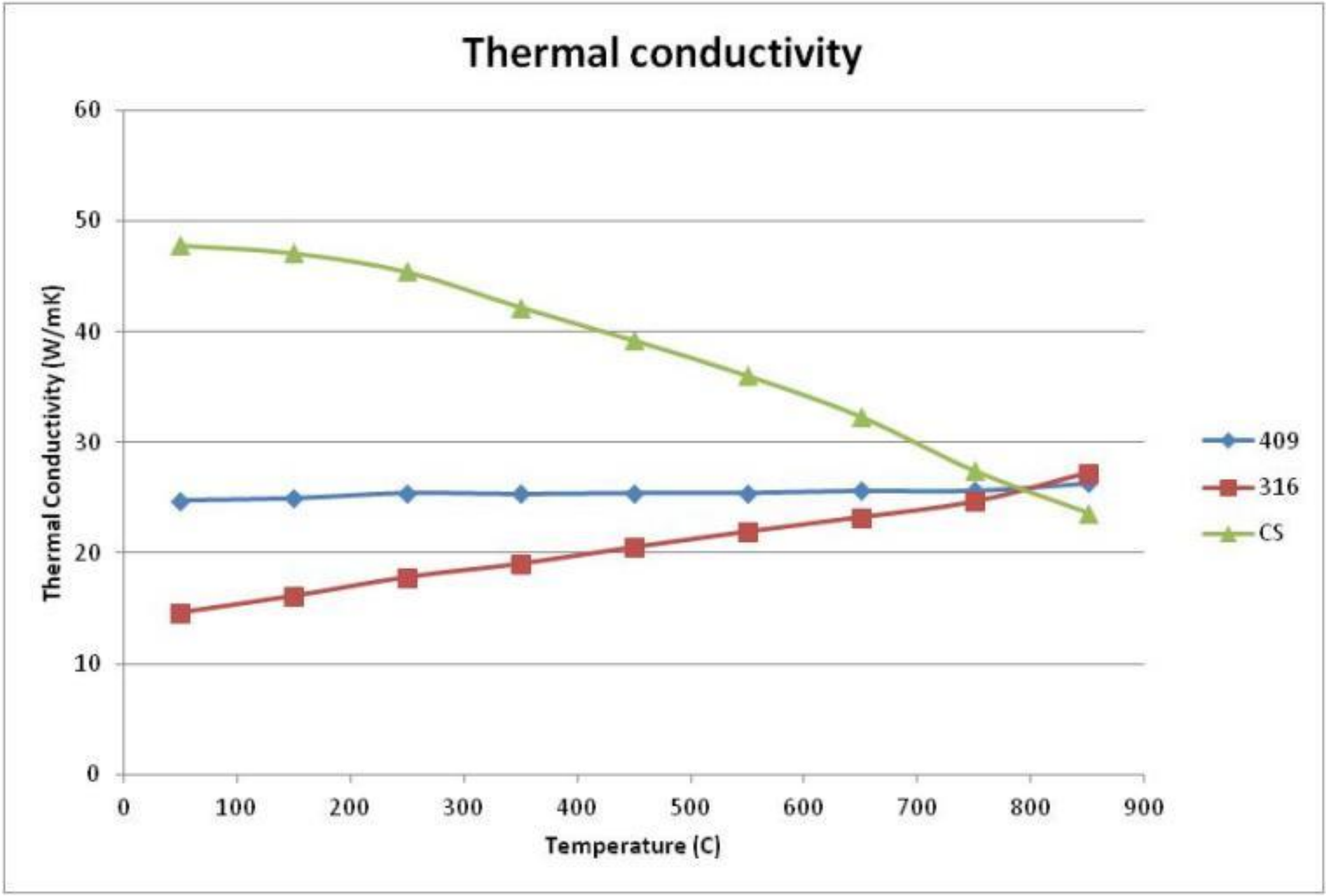


Fin Material

Tubesheets
<1050 F – Chromoly
1050 – 1400 F – 347SS
1400 – 1500 F – NO6617

Steam Headers
P22 or P91

Fin Material Considerations



Design Limits

CS < 454 C

409SS < 593 C

316SS < 871 C

Corrosive duty must be considered as well

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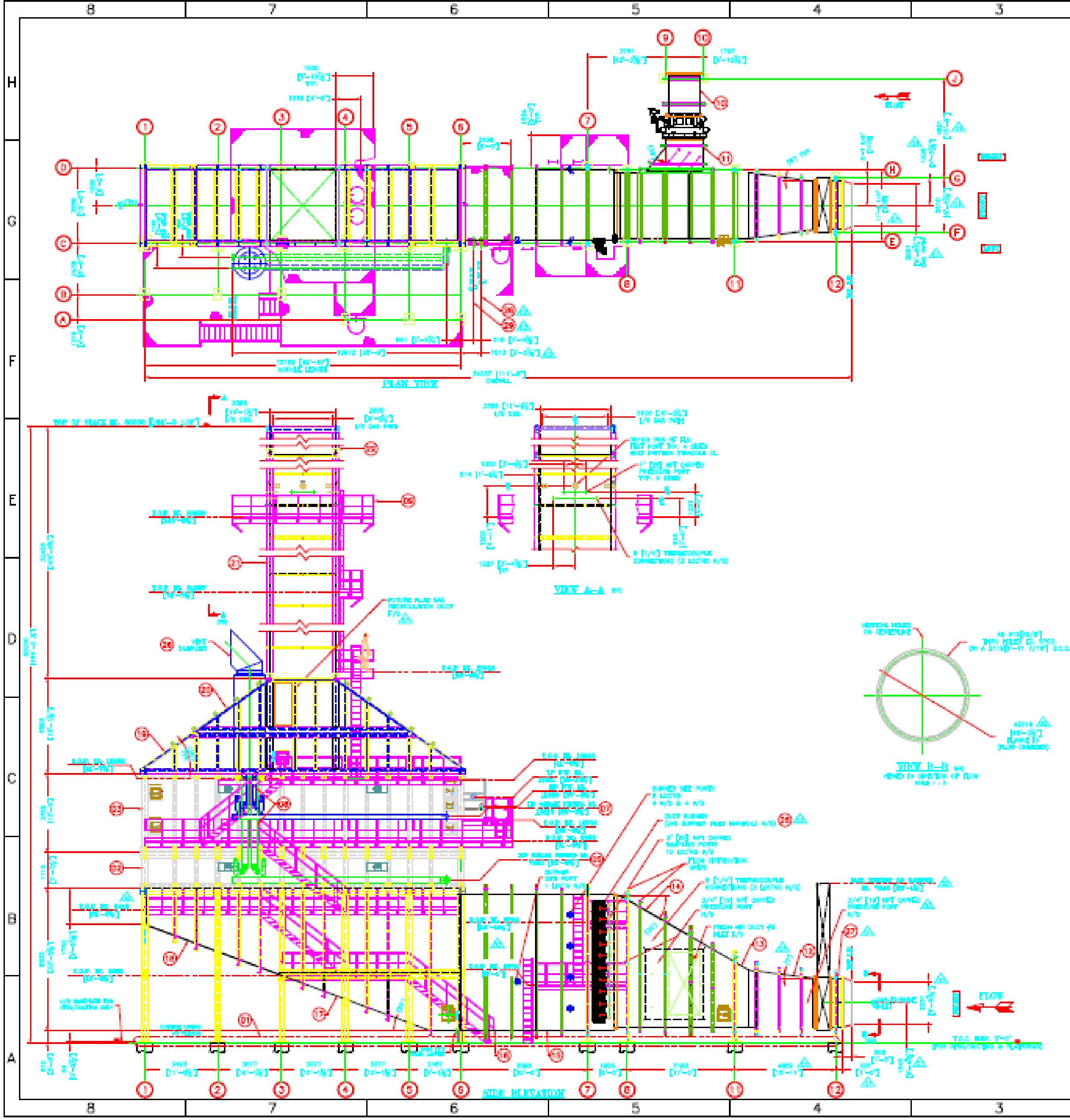
Fresh Air Firing – Case Study

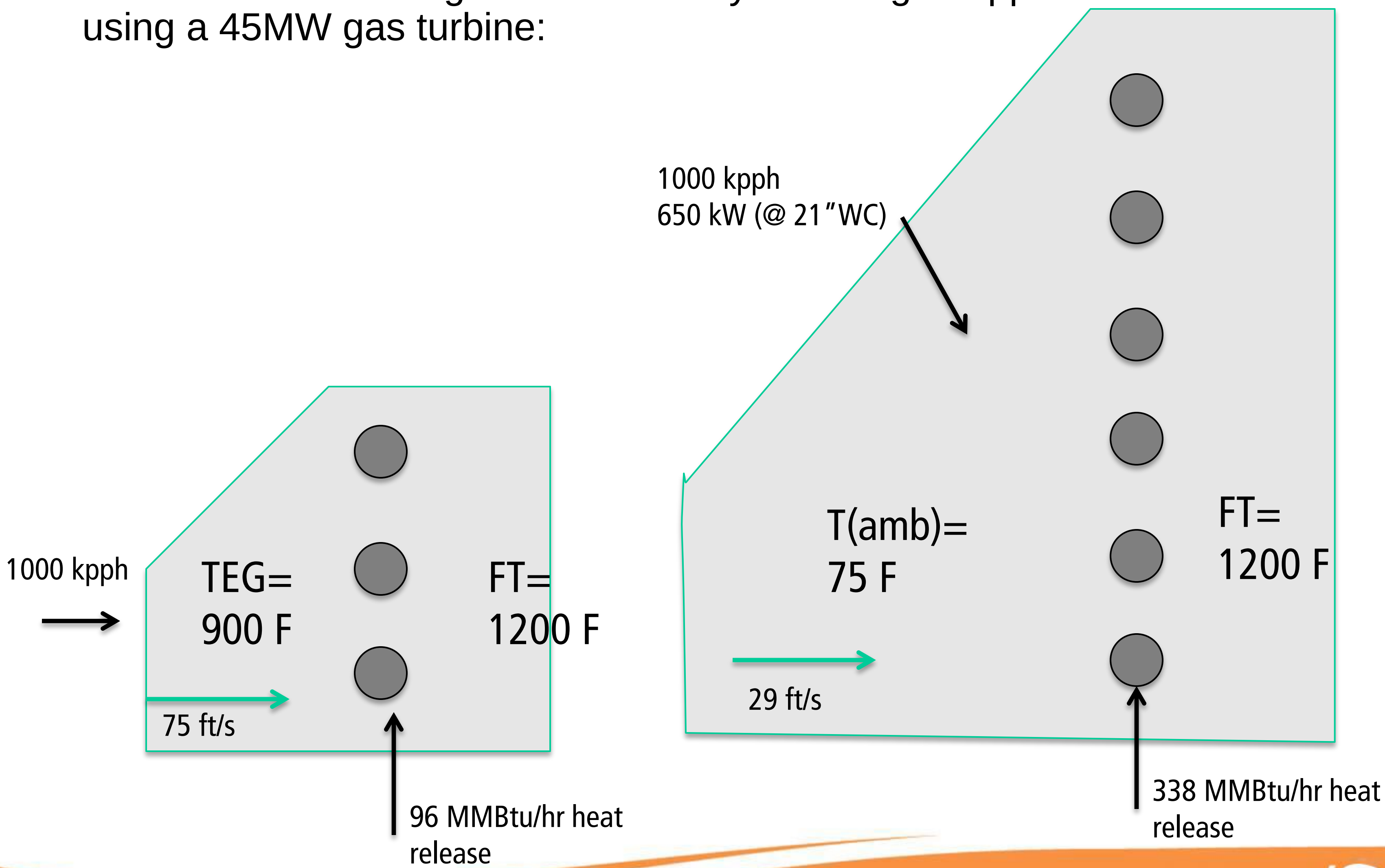
Fresh Air Firing

- Use a Forced Daft Fan and Duct Burner combination to simulate the gas turbine exhaust during a GT outage.
- Common in cogen applications where an uninterrupted steam supply is paramount.
- The duct burner is near identical to a traditional duct burner with minor modifications to the airfoil.
- Low water content in ambient air reduces the available energy.



Fresh Air Firing

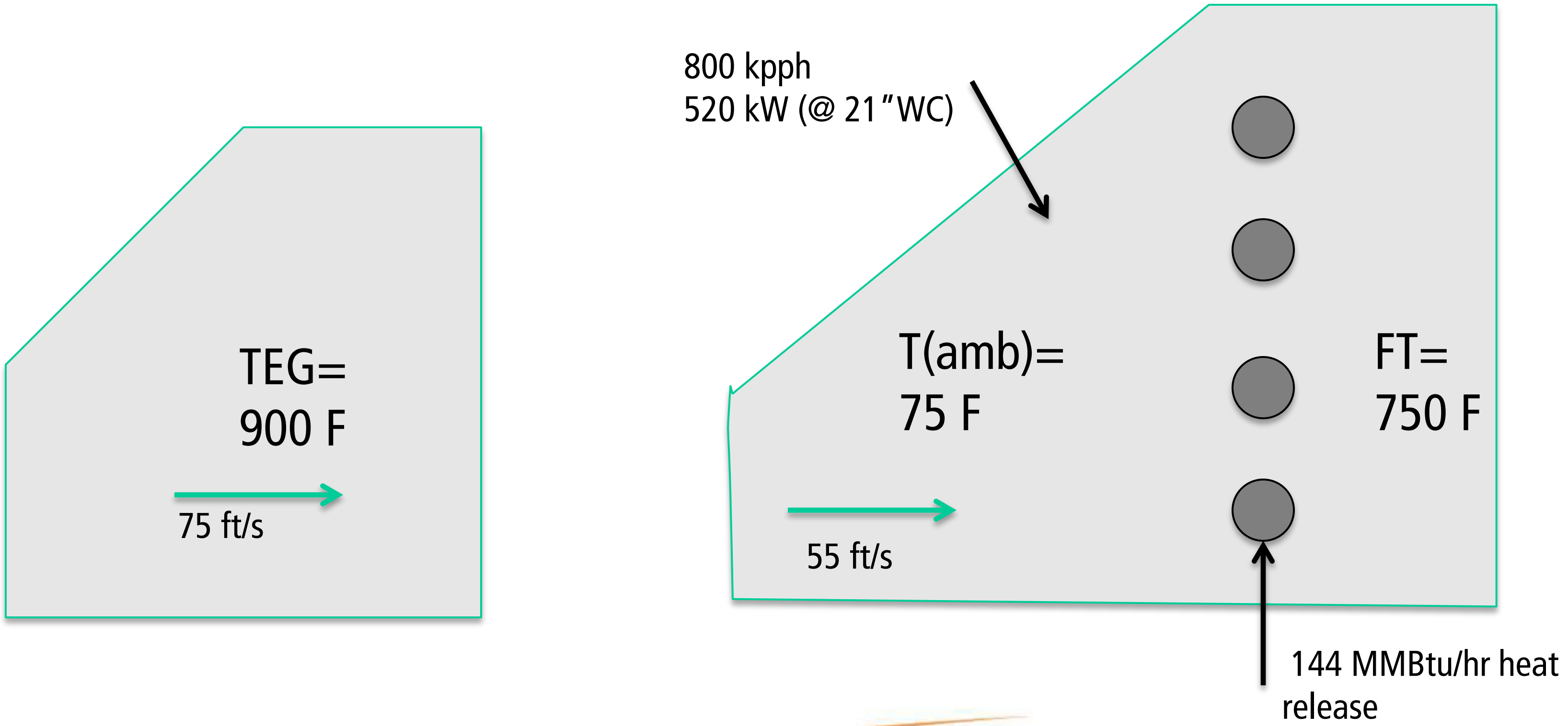
- Consider the following FAF case study for a cogen application using a 45MW gas turbine:



Fresh Air Firing

- Conclusion: Managing the flu gas velocity and peak heat release in FAF mode is a considerable challenge. The capital investment and parasitic load associated with the fan often pushes projects toward direct fired aux boilers.

- The compromise:
  - Generate partial steam supply in the FAF case (70 – 80% of unfired capacity)



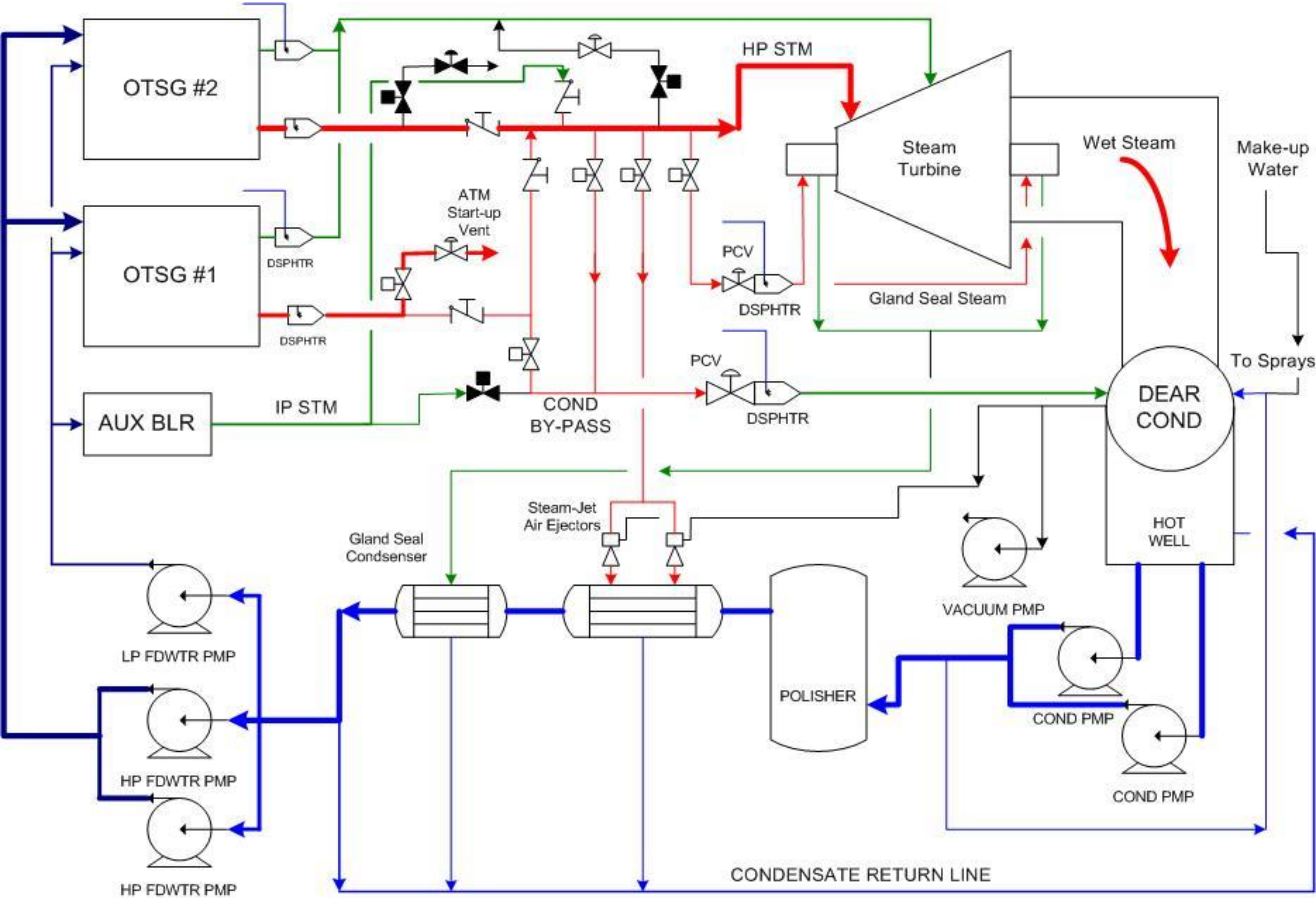
Balance of Plant Considerations

OPTIMAL STEAM LOOP B.o.P.:

1. Maintain Condensate Loop Vacuum during overnight shutdowns (requires auxiliary boiler)
   - Fastest start due to STG thermal gradient, gland steam, and water chemistry

2. ST- Condenser should be spec'd for part load operation (larger vacuum pumps)
   - Allows gas removal from condensate in turndown modes

3. Dedicated ST Condenser By-passes
   - Minimize water consumption during frequent starts and multi-unit configurations



OPTIMAL OTSG CC PLANT
CONFIGURATION

Fastest Ramping CC in the World

Escatron

Tecnicas Reunidas SA, Zaragoza, Spain

- 4x LM6000 & 4x OTSGs
- Duct fired to 1088 F
- Load ramp from 50% to 100% in 100 seconds

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Thank you for your time