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Directorate-General for
Energy & Transport

Ministry of Industry an Energy
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Secretariat General

EU-GCC Seminar:
"Natural Gas Technologies – Realities & Prospects"
Doha, Qatar, 7-8 February 2005

STREAM B:
"Advanced Technologies for Power Generation through Natural Gas & Desalination"

SESSION B.3:
STATE OF THE ART OF COMBINED CYCLE PLANT

Michael VOLLMER,
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ALSTOM Power Turbo-Systems

February 2005

Power Turbo-Systems

State Of The Art Combined Cycle Power Plants

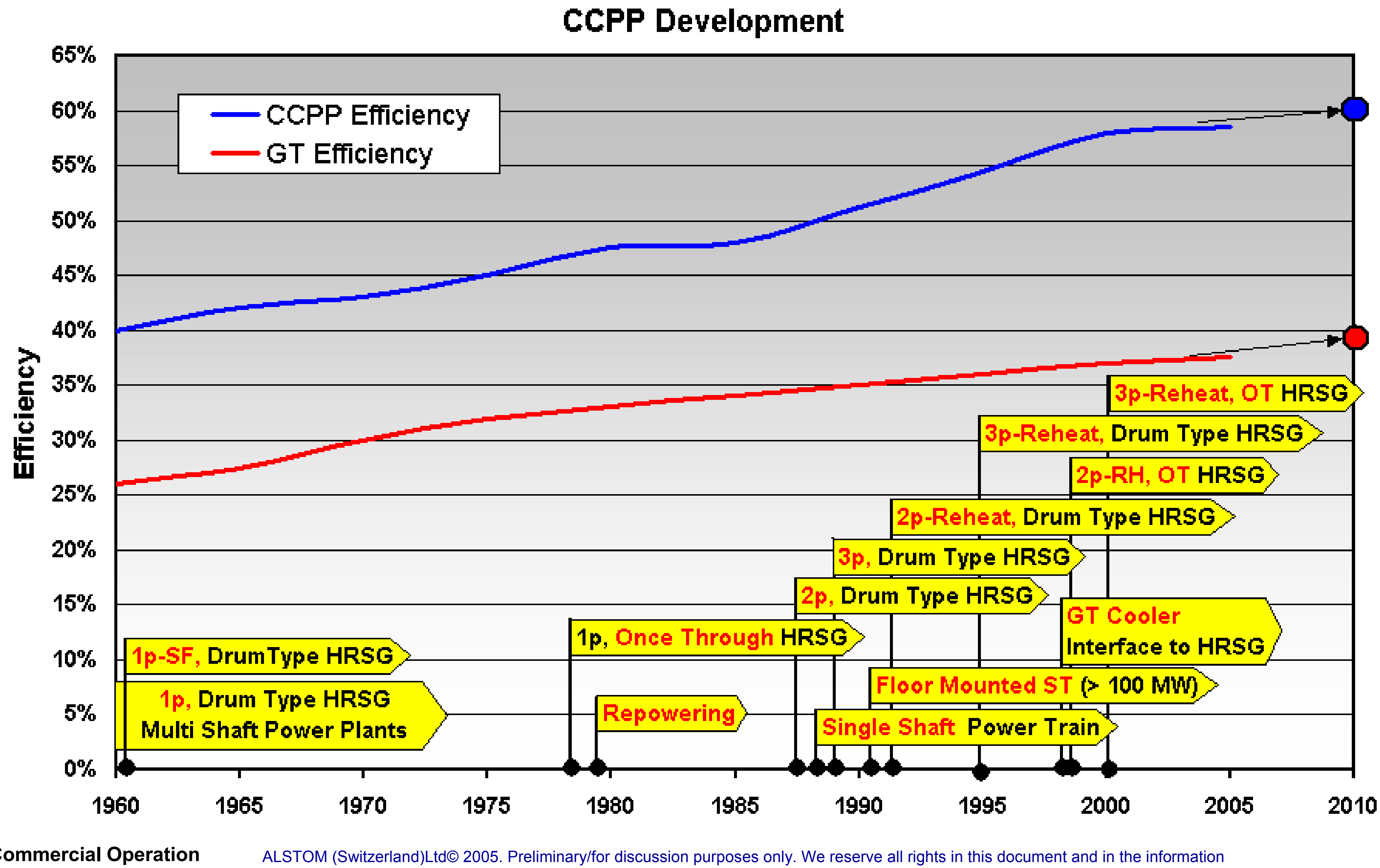
Michael Vollmer

ALSTOM

Agenda

- **Energy Market**
- **CCPP Selection & Optimisation**
  - **Plant Sizes**
  - **Optimisation Areas**
    - **Hot-End**
    - **Cold-End**
- **Advanced Cycle Concepts**
- **Plant Start-Up**
- **Layouts**
- **Perspectives**

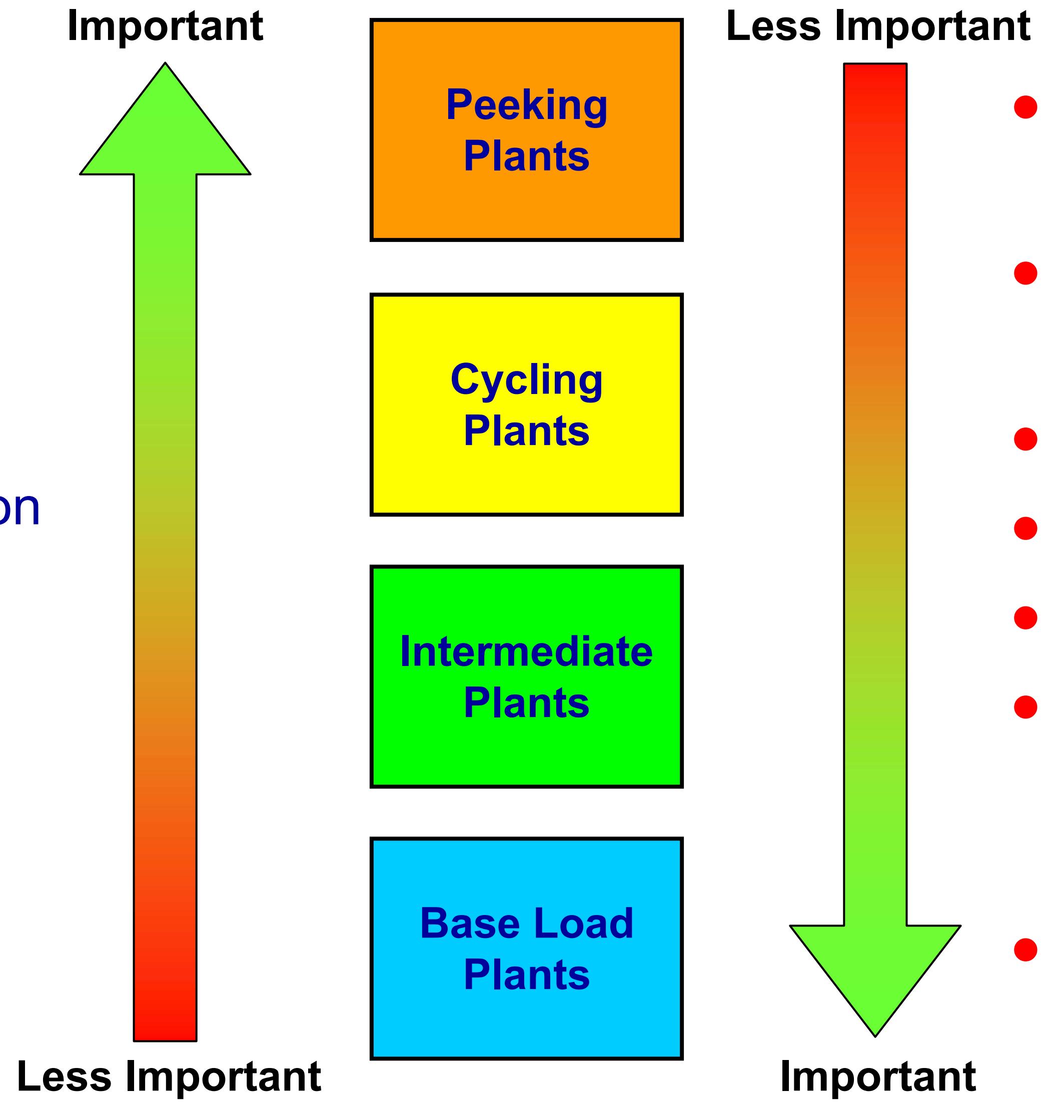
Energy Market
CCPP Historical Development



Energy Market

Requirements for Grid Stability

- Low specific cost per kW
- Small, decentralized power sizes
- Shortest installation / cycle time
- Fast and reliable start-up
- Cycling capability
- Flexible load ramping



- Low cost of electricity
- Large, centralized power sizes
- High availability
- High efficiency
- Low emissions
- Frequently used (base load application)
- Surety for grid stability

Energy Market
Fit of a Combined Cycle Power Plant

- Sizeable power range by using multiple units
- Attractive specific installation cost per kW (compared to alternative plant types)
- Short installation time (Typically between 20 and 26 months)
- Flexible in design to gain maximum profit
  (Mainly depending on fuel price and demanded operating hours per year)
- Low emissions (CO_2, NOx, CO, SO_2, Particles) due to the use of natural gas as main fuel, high net efficiencies of the plant and sequential combustion
- Possibility to be build in phased construction (SSPP ⟶ CCPP)
- High operational flexibility (fast start-up, cycling, frequency support, etc.)
- High degree of automation
  (limited number of people needed for operation, daily maintenance and administration)
- Capability for special features and applications
  - Power augmentation
    - GT: Air inlet cooling, steam/water injection, peak operation
    - HRSG: Duct firing, inter-stage firing, fresh-air assisted supplementary firing
  - Conversion of uneconomic steam plants into CCPP (Repowering)
  - Co-generation (District heating, process steam export, desalination, etc.)

State of the Art CCPP
Agenda

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Combined Cycle Power Plants
Selection & Optimisation

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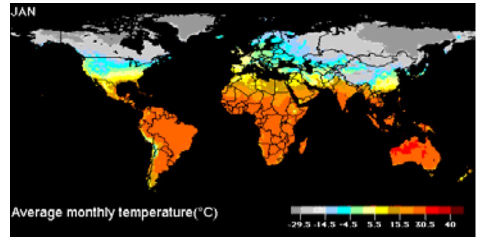
Regulatory Conditions

- Grid code
- Permitting process
- Emission
  (Flue gas, heat, plume, noise, waste water)
- Standards and codes for design
- Architectural constraints

Site Conditions

- Climatic and topographic conditions
- Space availability
- HV interconnection / Grid size
- Access to site (Transport concept)
- Water and air quality
- Soil conditions
  (e.g. bearing capacity)



Commercial Conditions

- Financial budget, partner set-up
- Fuel- and energy price
  (FSA, PPA, Merchant, Spot, …)
- Insurance
  (Transport, erection; operation)
- Installation / cycle time
- Payment schedule
- Labor rates, skills and productivity
- Maintenance, spare parts
- ROI, payback period, taxes
- Lifetime

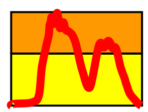
CCPP Selection & Optimisation

Component Integration

- Best fit of components & technologies
- Supplier and sourceing concept
- Improvement and development of standard components

Operational Conditions

- Plant performance
- Ancillary services
- Operation regime
  (Utilization OH/a, load ramps, yearly starts/stops)
- Degree of automation
- Training, simulation, monitoring



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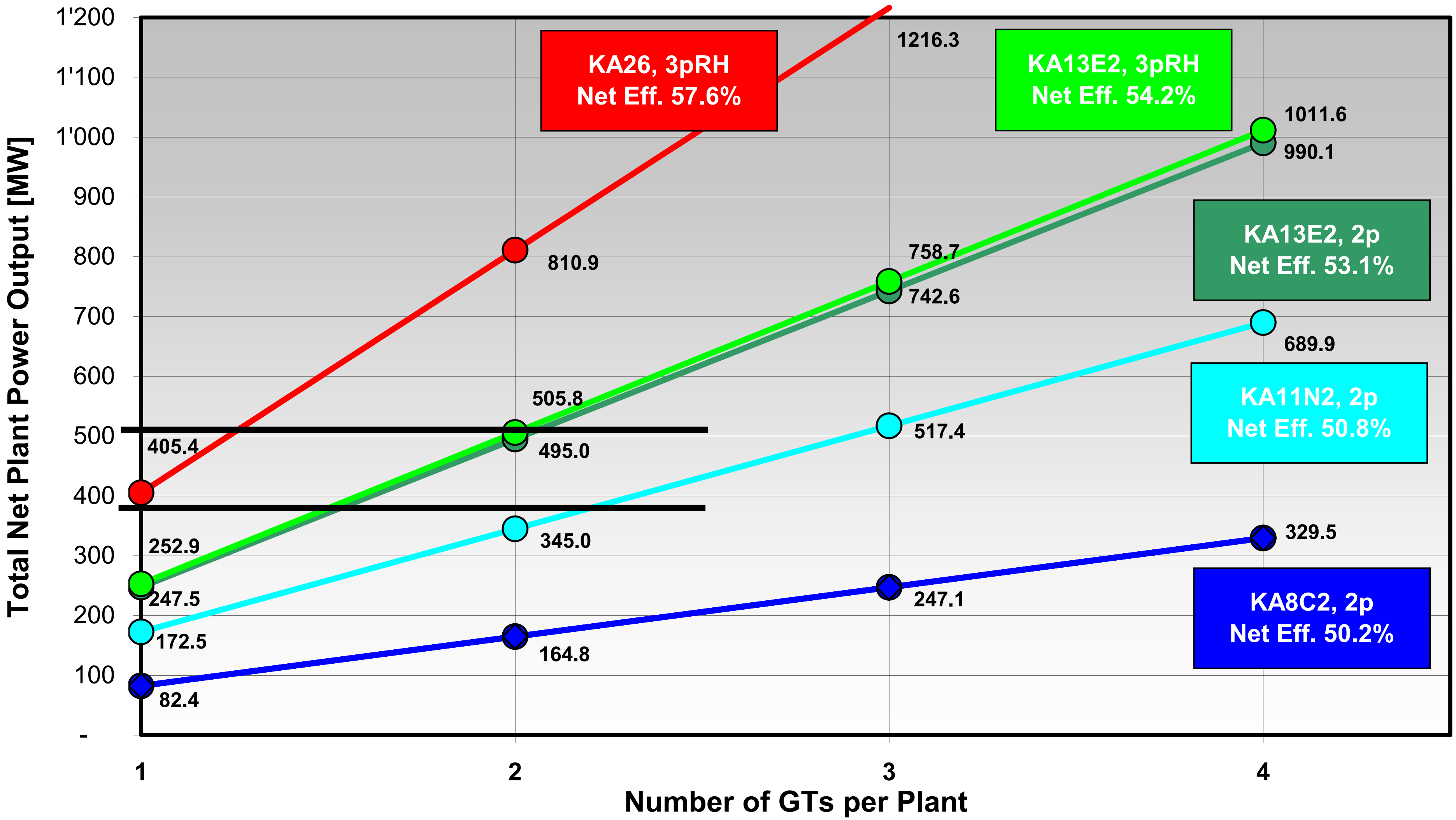
Combined Cycle Power Plants

Selection of the Plant Size

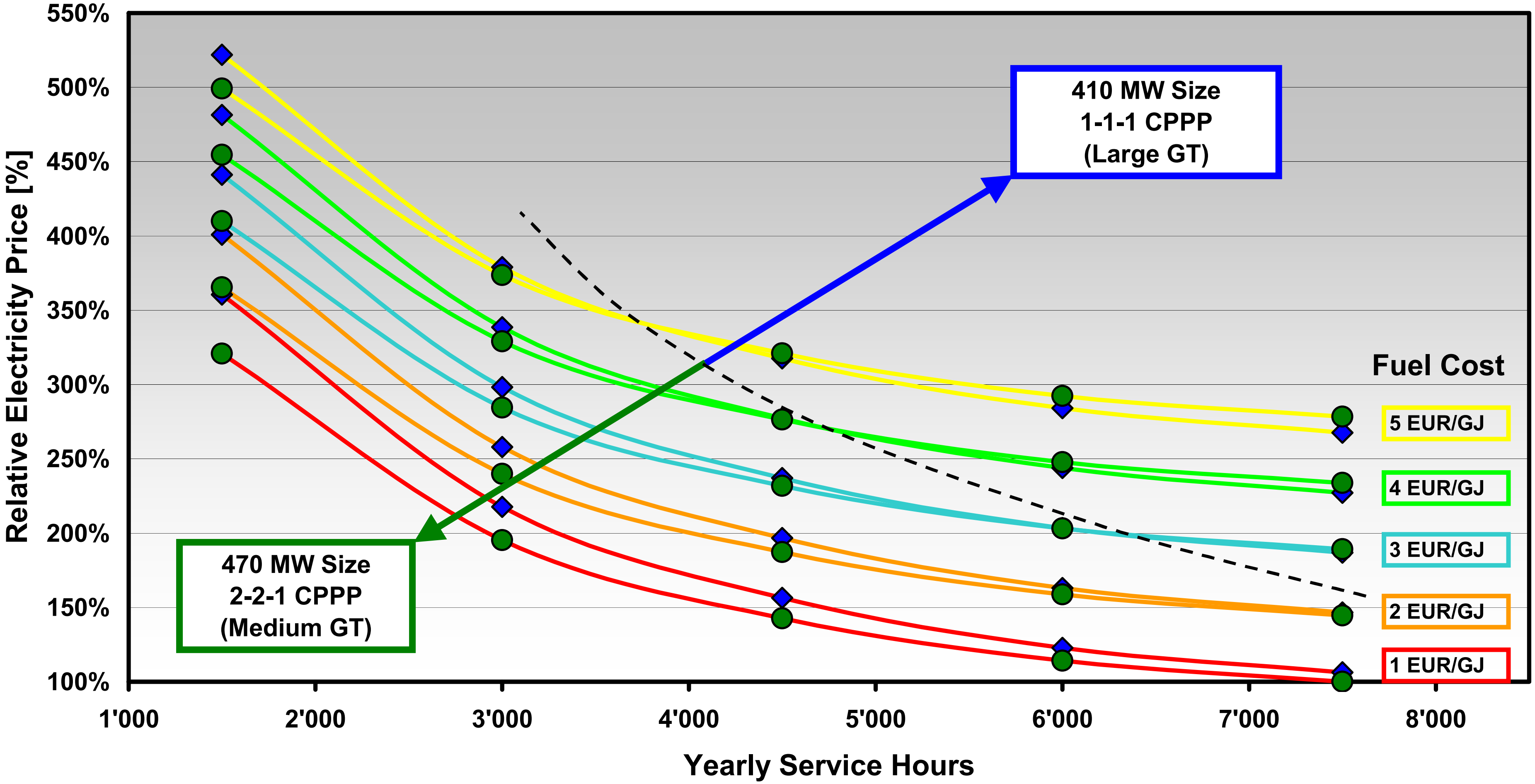
KA Series 50 Hz (ISO Conditions, Condenser Pressure 45 mbar)



Combined Cycle Power Plants
Economic Comparison

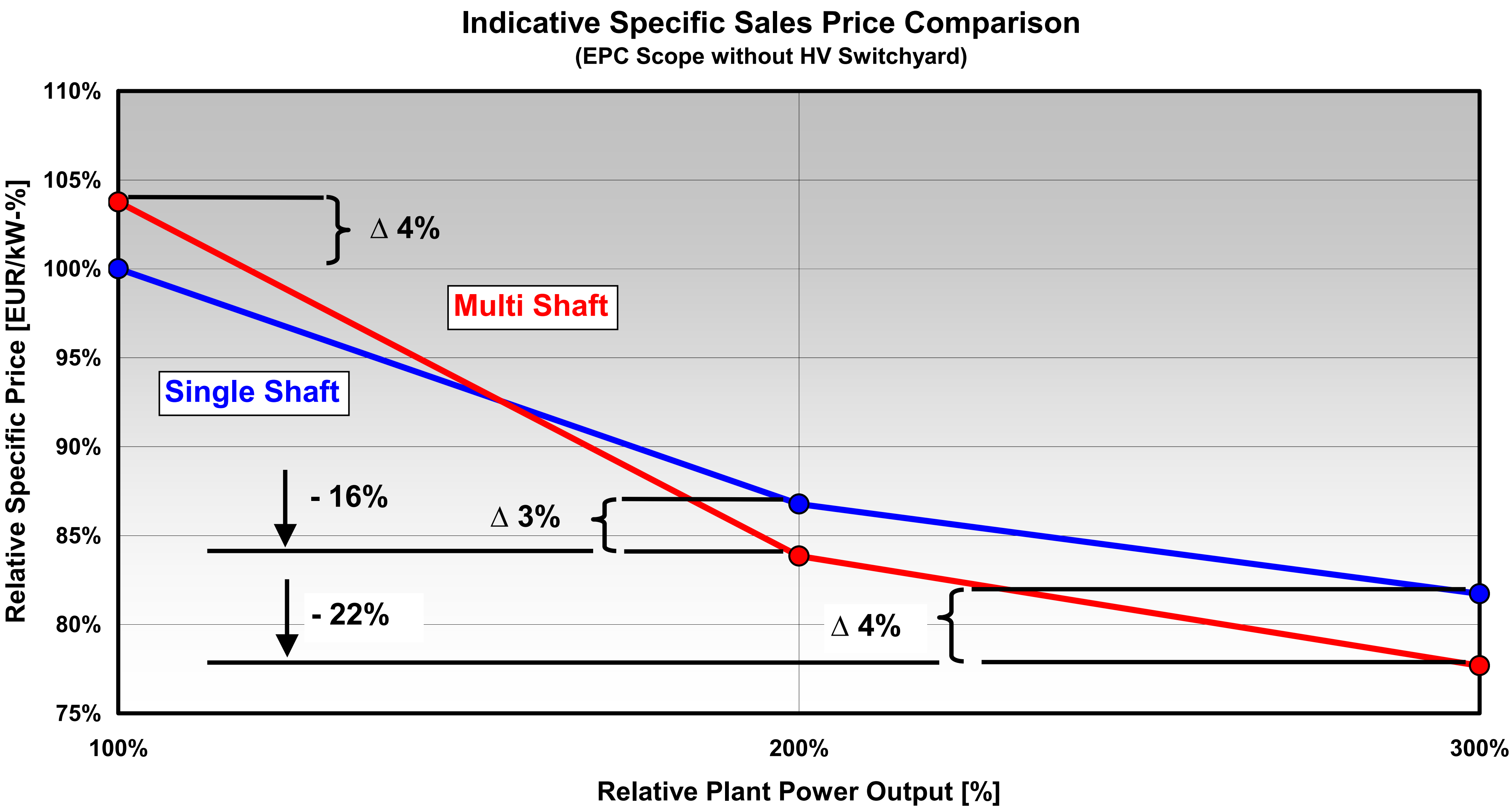
ALSTOM

Selection of the Gas Turbine Model and Plant Configuration in a Power Range of 400 - 500 MW



Combined Cycle Power Plants

Economic Aspects of Plant Sizes



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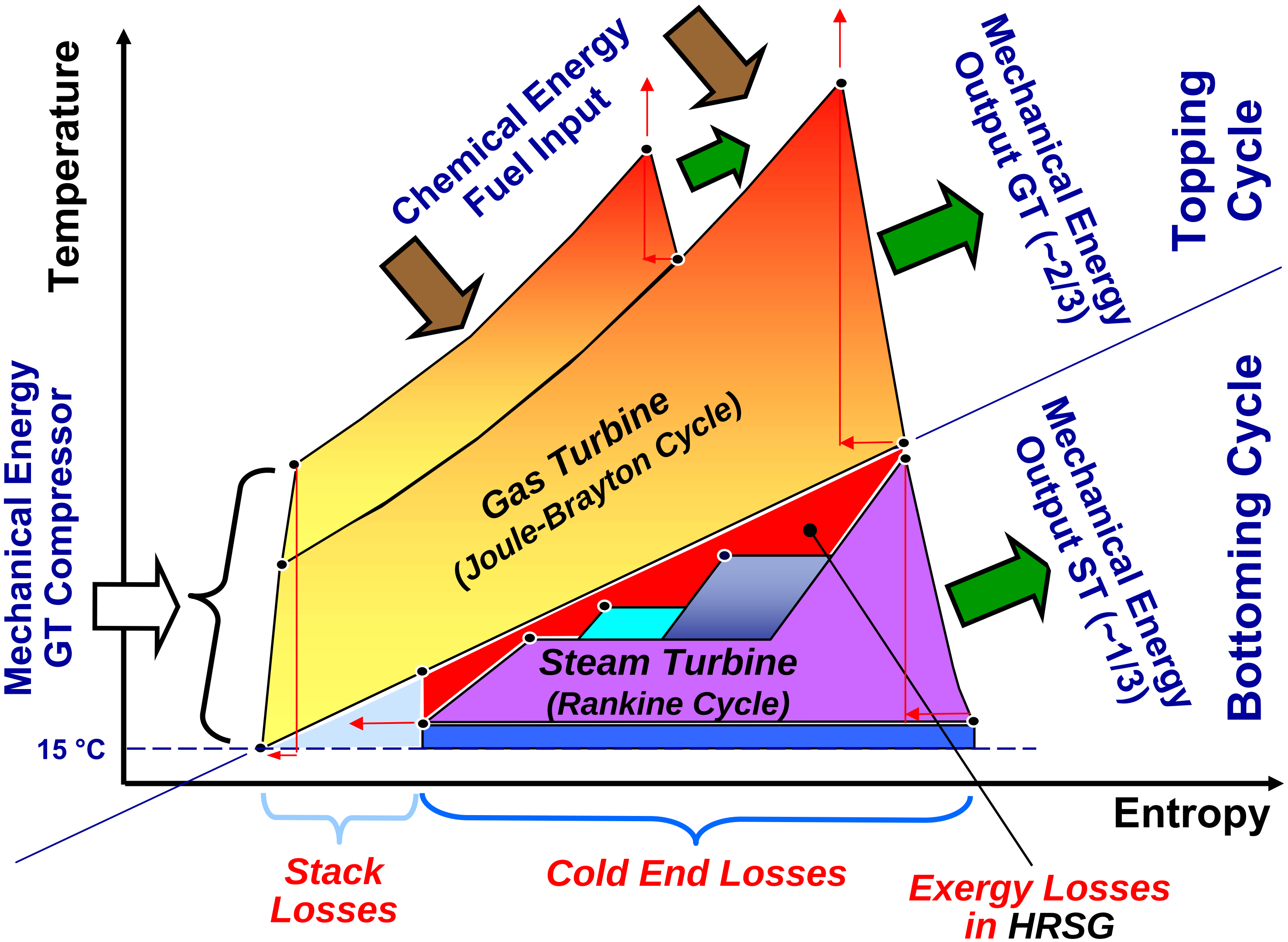
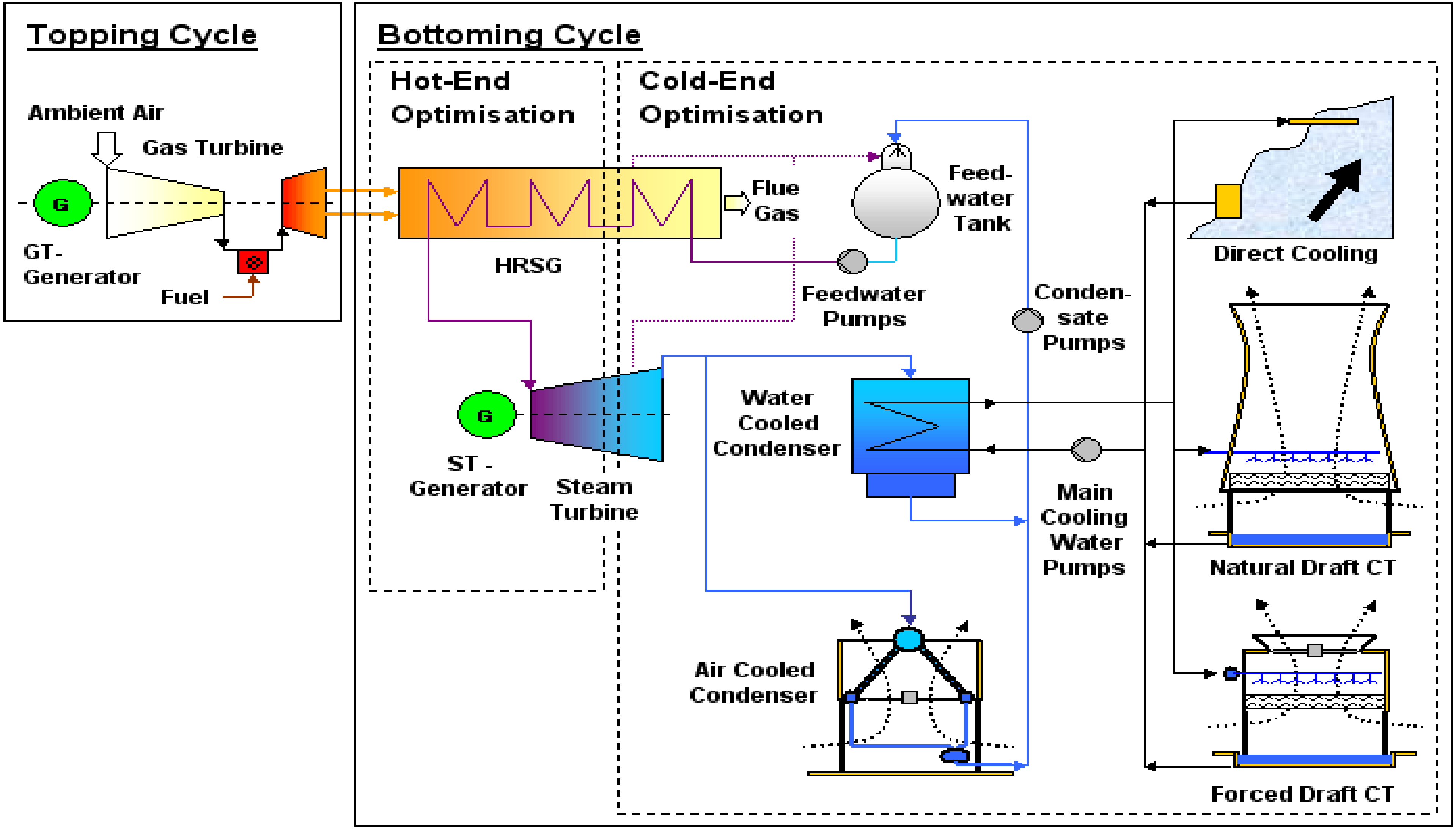
Combined Cycle Power Plants

Optimisation Areas (Thermodynamic View)



Combined Cycle Power Plants

Project Specific Optimisation



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Combined Cycle Power Plants
Hot-End Optimisation (2p-Cycle)

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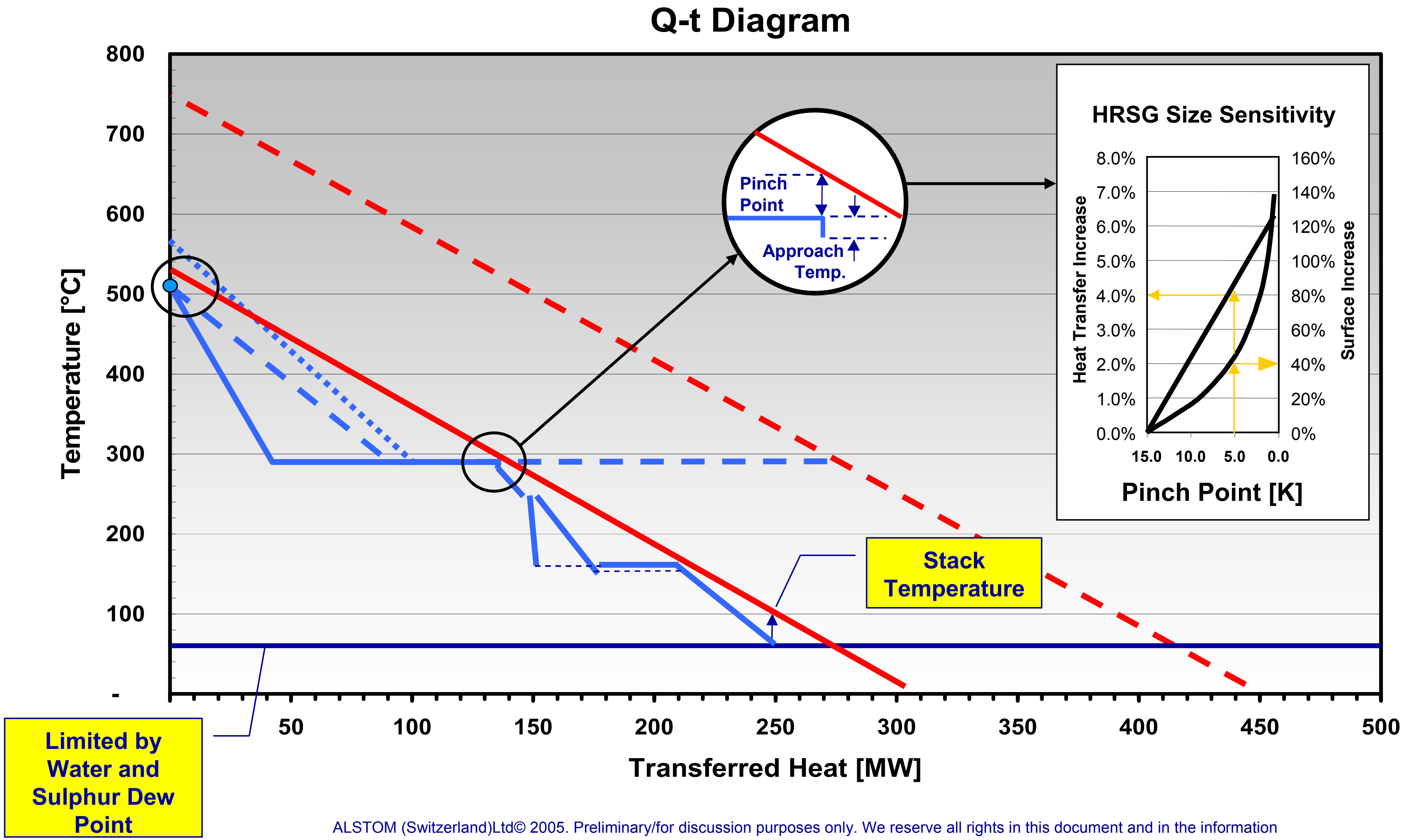
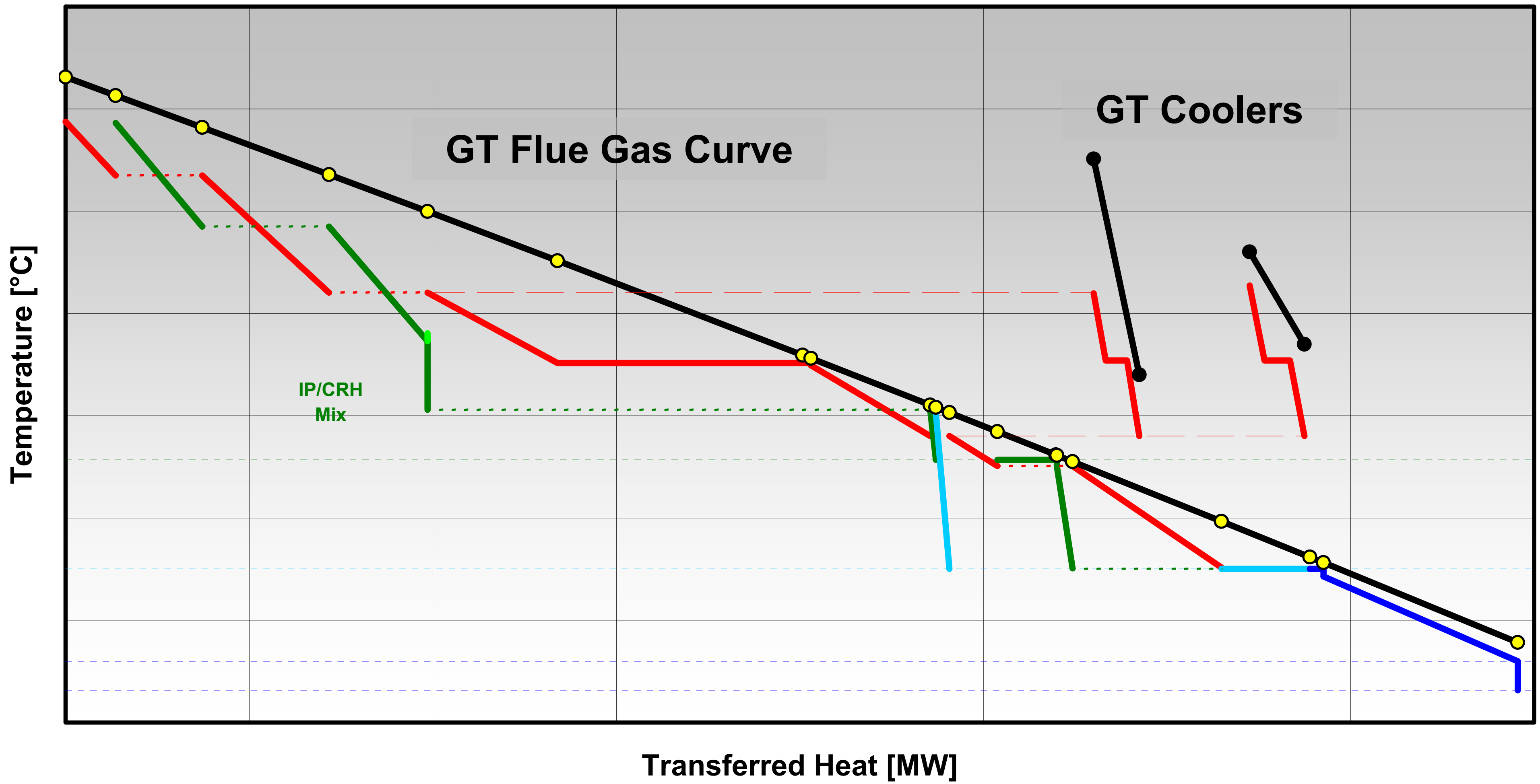


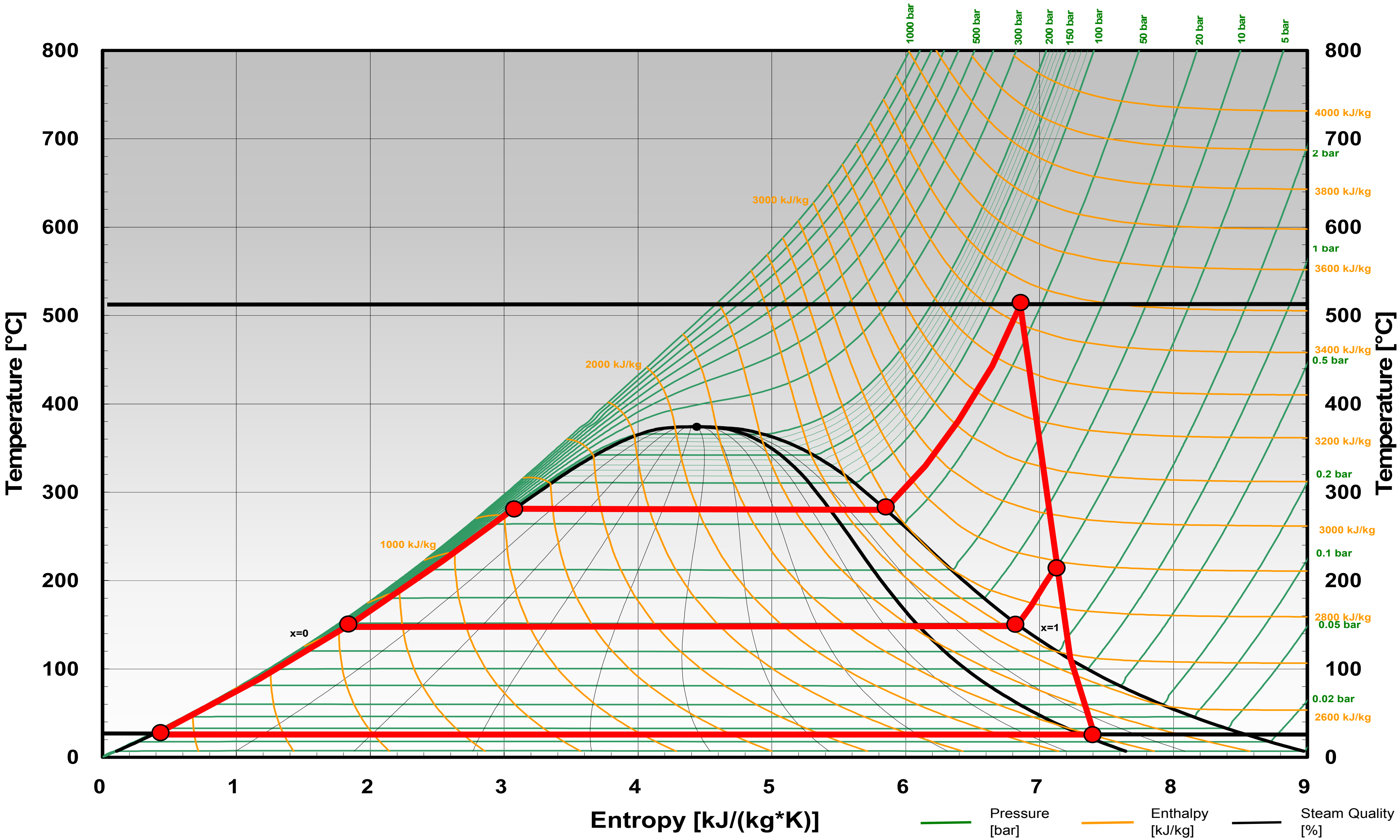
Combined Cycle Power Plants
Advanced 3p-RH Cycle

Q-t Diagram



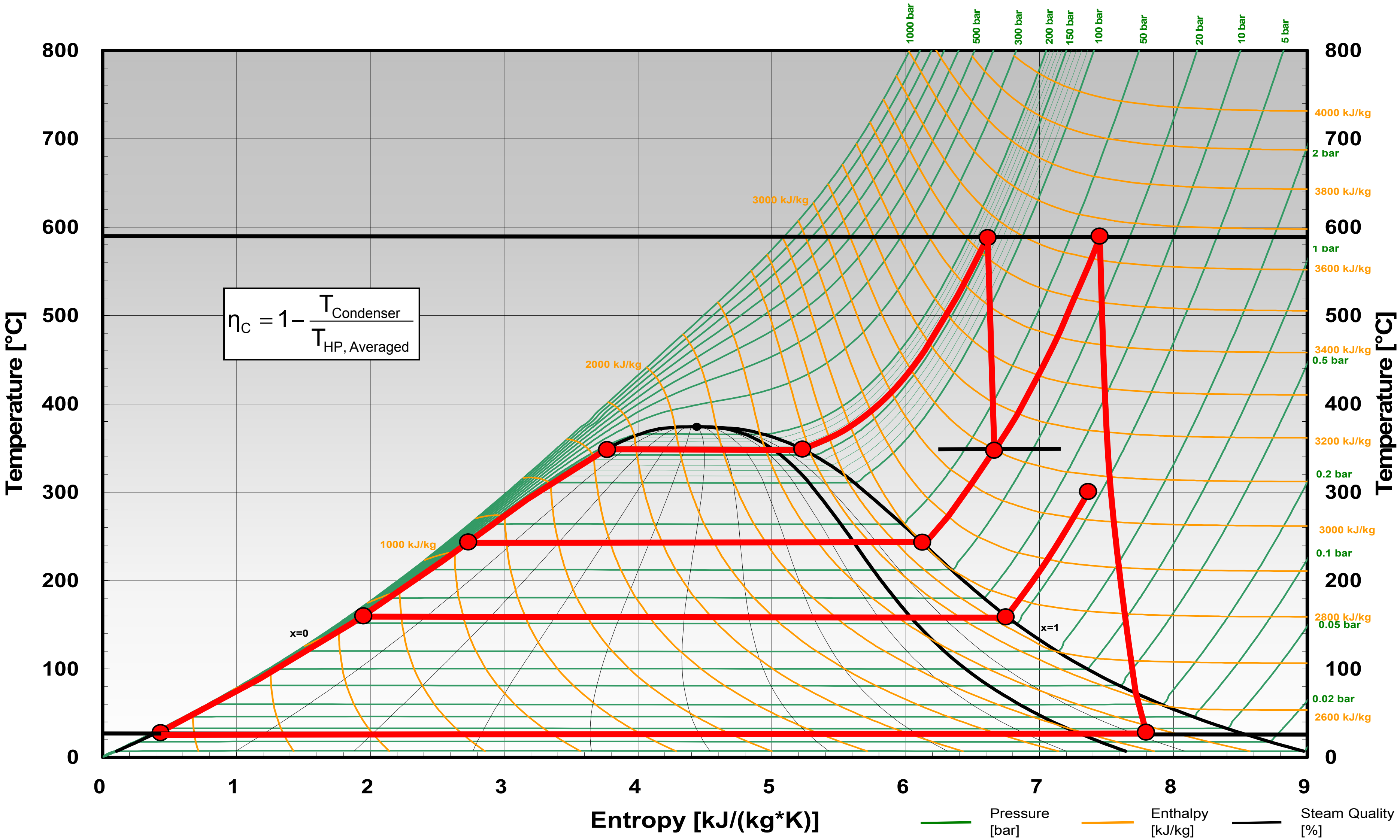
Combined Cycle Power Plants

Non-Reheat Cycle Optimisation



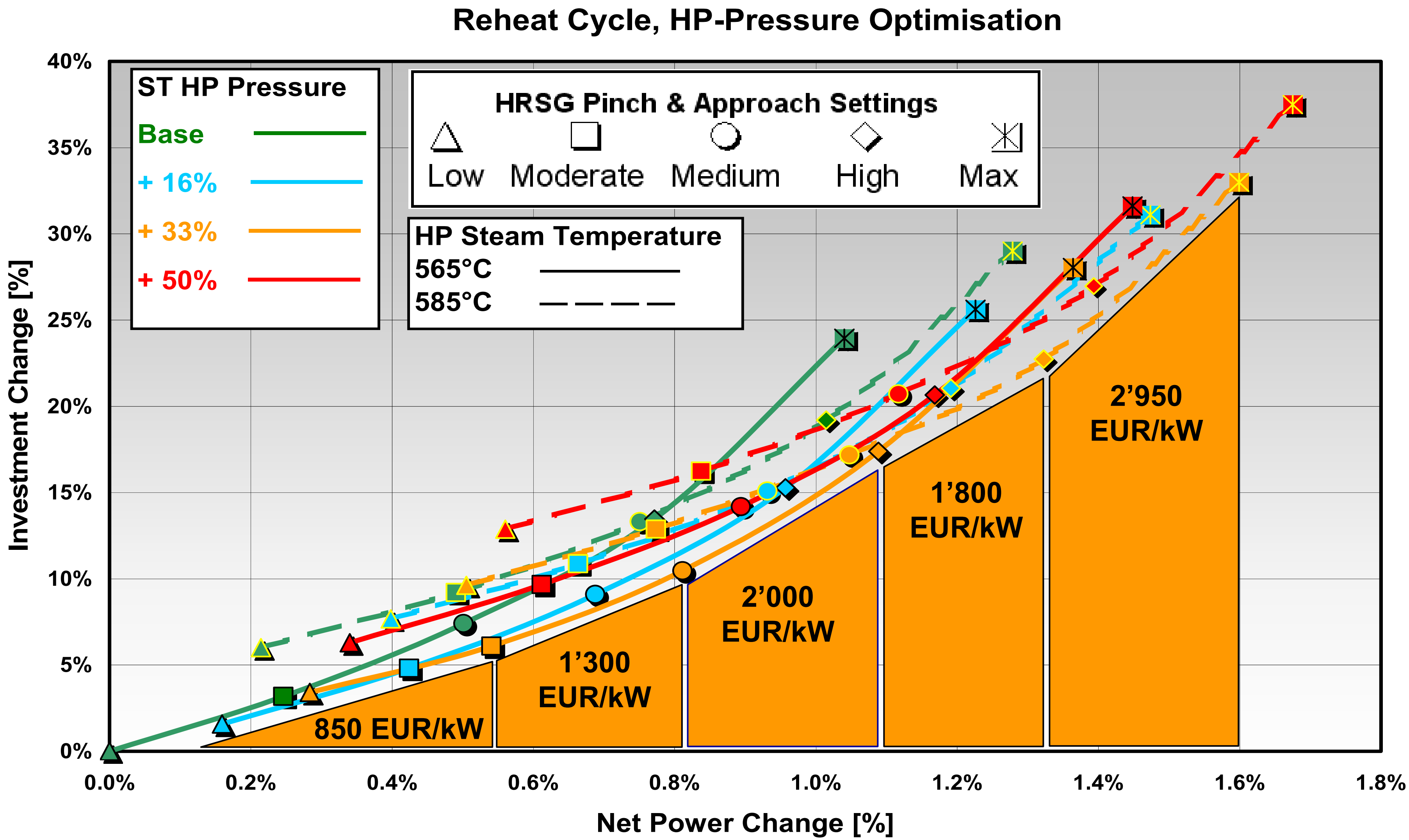
Combined Cycle Power Plants

Reheat Cycle Optimisation



Combined Cycle Power Plants

Reheat Cycle Economic Optimisation



Combined Cycle Power Plants
Heat Recovery Steam Generator

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	Horizontal HRSG	Vertical HRSG
Performance	Equal for same Price	
Start-Up Time, Cycling Capability, Response for Rapid Load Change	Equal	
Plot Plan Area for Equal Output	Base	Larger
Catalytic Emission System	Separate section increases total length. Easy later installation in pre-designed provisions. Faster and easier replacement of catalyst elements (shorter down-time).	Requires increased total height. Ammonia particulate more difficult to remove. More complex later installation.
Supplementary Firing	Readily installed within inlet duct or within surface	Limited to moderate levels of supplementary firing
Indoor Installation	Separate freestanding enclosure	Easily to be attached to existing steel structure
Circulation	Natural. No pumps.	Natural. Start-up pumps may be required.
Others	Suitable for high seismic locations	Suitable for retrofit into existing boiler houses
	Requires heavy cranes during construction	Blow down tank above ground allowing geodetically drain

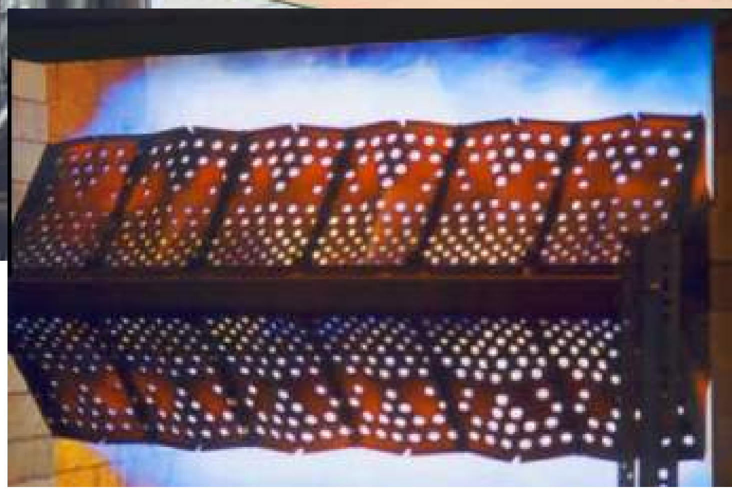
Combined Cycle Power Plants

HRSG Features

Bypass Stack

Fresh Air System

Common Exhaust Stacks



Duct Firing

Catalysts

Hot-End Summary

- The economic HP pressure optimum is not sensitive to the selected pinch points and approach temperatures of the HRSG and therefore a pure balance between
  - Increase of cycle efficiency by going to higher pressure levels
  - Decrease of steam turbine efficiency with decreasing volume flow
  - Auxiliary power consumption change of the feed-water pumps
- The economic HP pressure optimum tends to be higher for Air Cooled Condenser (ACC) applications (⟶ less heat rejection)
- The optimum IP/RH pressure level is linked to the upper averaged temperature level of the selected HP
- The LP pressure level drives the energy losses at the stack
- Duct firing is a cheap alternative to boost power without sacrificing the efficiency by also rising the steam temperatures

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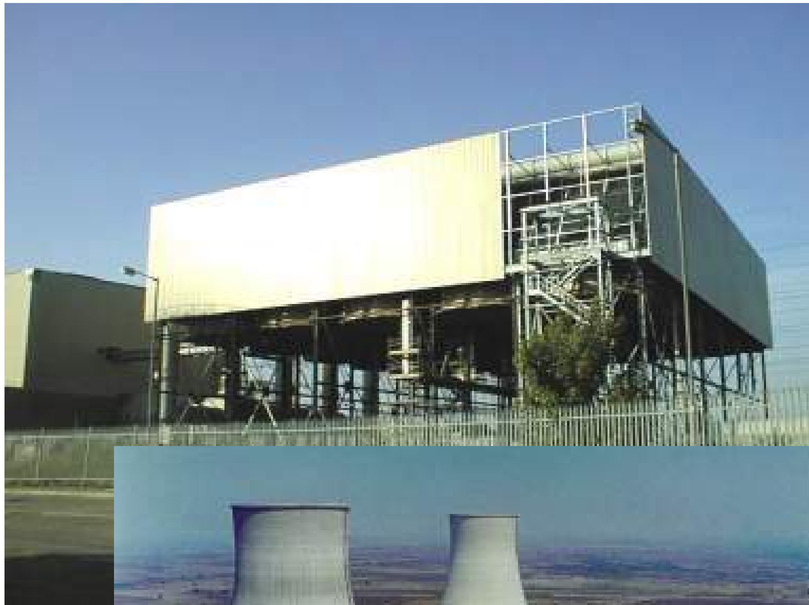
Combined Cycle Power Plants

Cold-End Optimisation

Air Cooled Condenser



Mechanical Draft Wet Cell-Type Cooling Tower

Natural Draft Circular Cooling Towers

Direct Cooling

Cold End Optimization

ST-LP Module Selection

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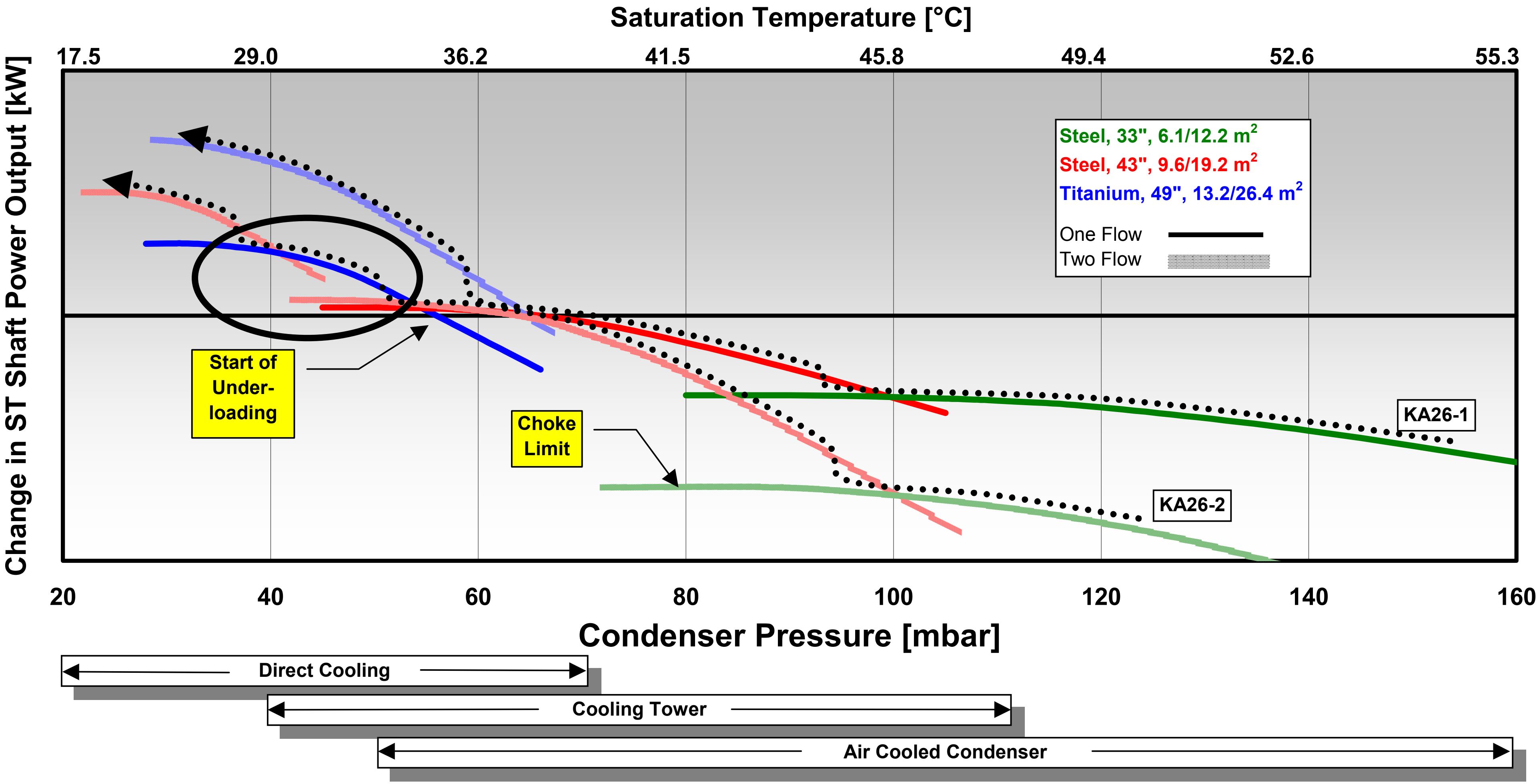
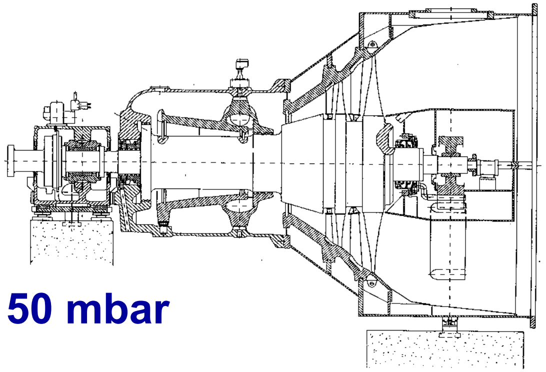
Operational Ranges of the ST Low Pressure Modules for a given KA26 Hot-End Optimisation



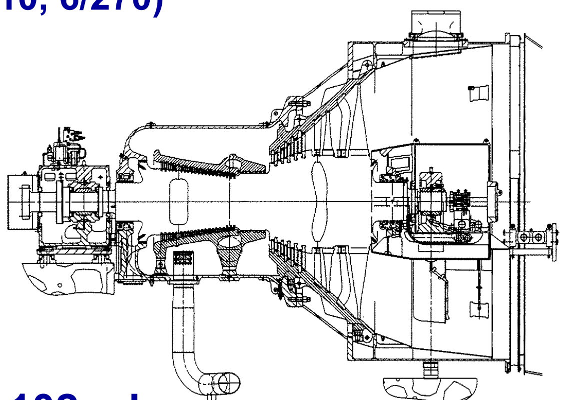
CCPP Selection and Optimization

Steam Turbine Module Combinations

Reverse Flow Turbines

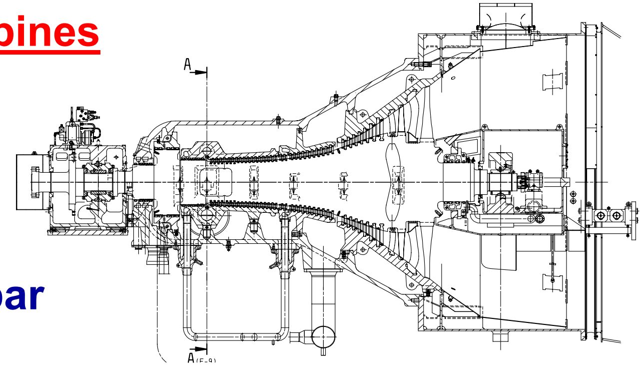


85 MW, pω 50 mbar
2p Cycle
(bar/°C: 65/510, 6/270)

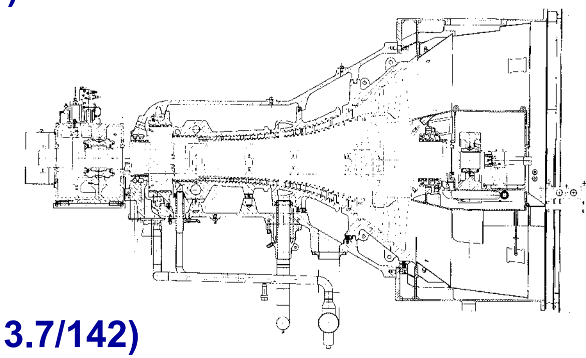


163 MW, pω 102 mbar
2p Cycle
(bar/°C: 72/510, 5.5/270)

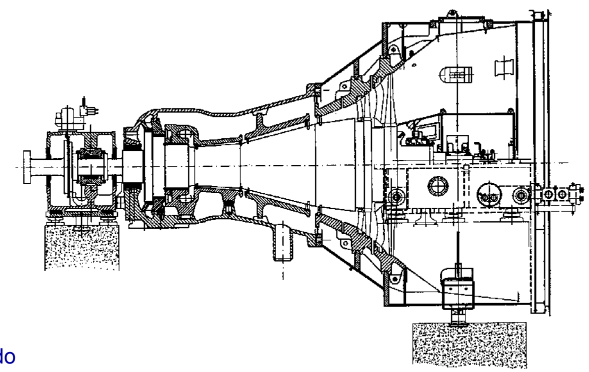
Single Flow Turbines



57 MW, pω 90 mbar
2p Cycle
(bar/°C: 70/480, 6.4/240)



82 MW, pω 97 mbar
3p Cycle
(bar/°C: 98/508, 25/507, 3.7/142)

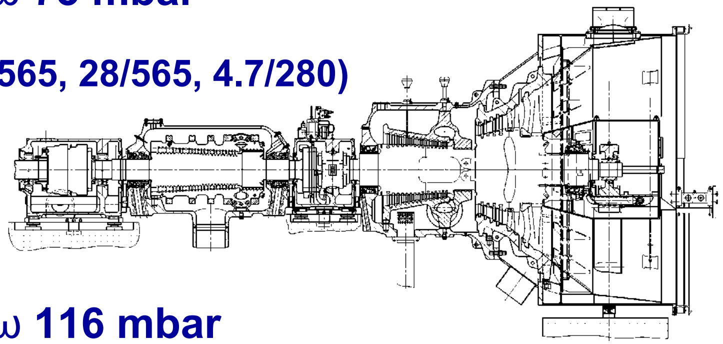


126 MW, pω 80 mbar
2p Cycle
(bar/°C: 71/521, 6.1/268)

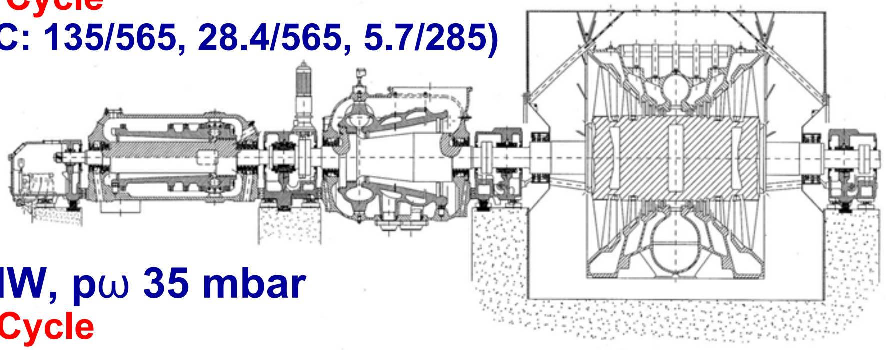
CCPP Selection and Optimization
Steam Turbine Module Combinations

Reheat Turbines

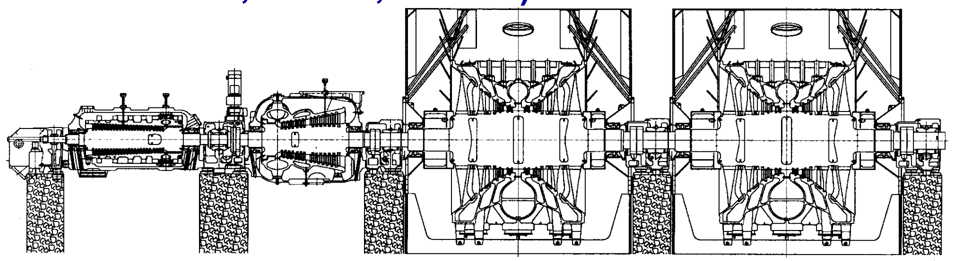
154 MW, pω 73 mbar
3pRH Cycle
(bar/°C: 133/565, 28/565, 4.7/280)



300 MW, pω 116 mbar
3pRH Cycle
(bar/°C: 135/565, 28.4/565, 5.7/285)

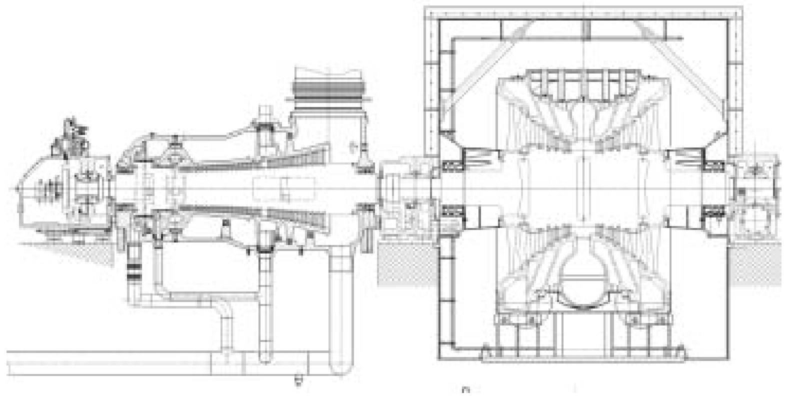


322 MW, pω 35 mbar
3pRH Cycle
(bar/°C: 120/565, 25/565, 4.6/289)

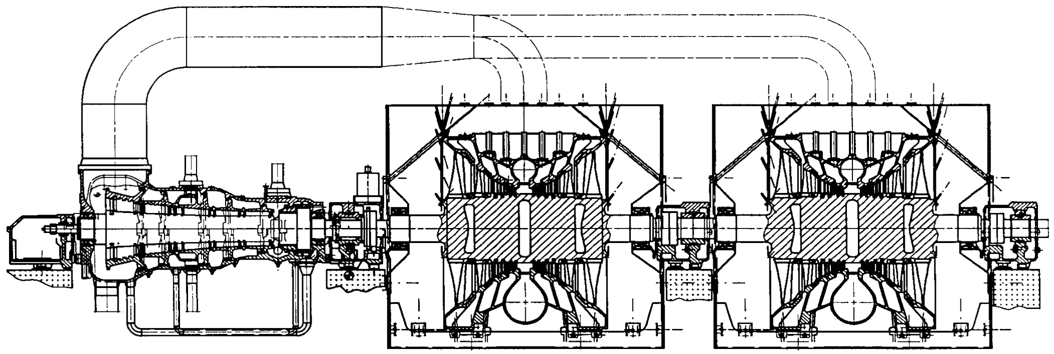


Non-Reheat Turbines

175 MW, pω 79 mbar, 3p Cycle
(bar/°C: 94/515, 24/514, 4.4/149)



258 MW, pω 30 mbar, 2p Cycle
(bar/°C: 107/510, 3.8/142)



Cold-End Summary

- Reducing the condenser vacuum is a cheap and safe mean to gain additional power and overall plant efficiency
- The number of steam turbine low pressure flows can be minimised by going to larger last stage blades

State of the Art CCPP
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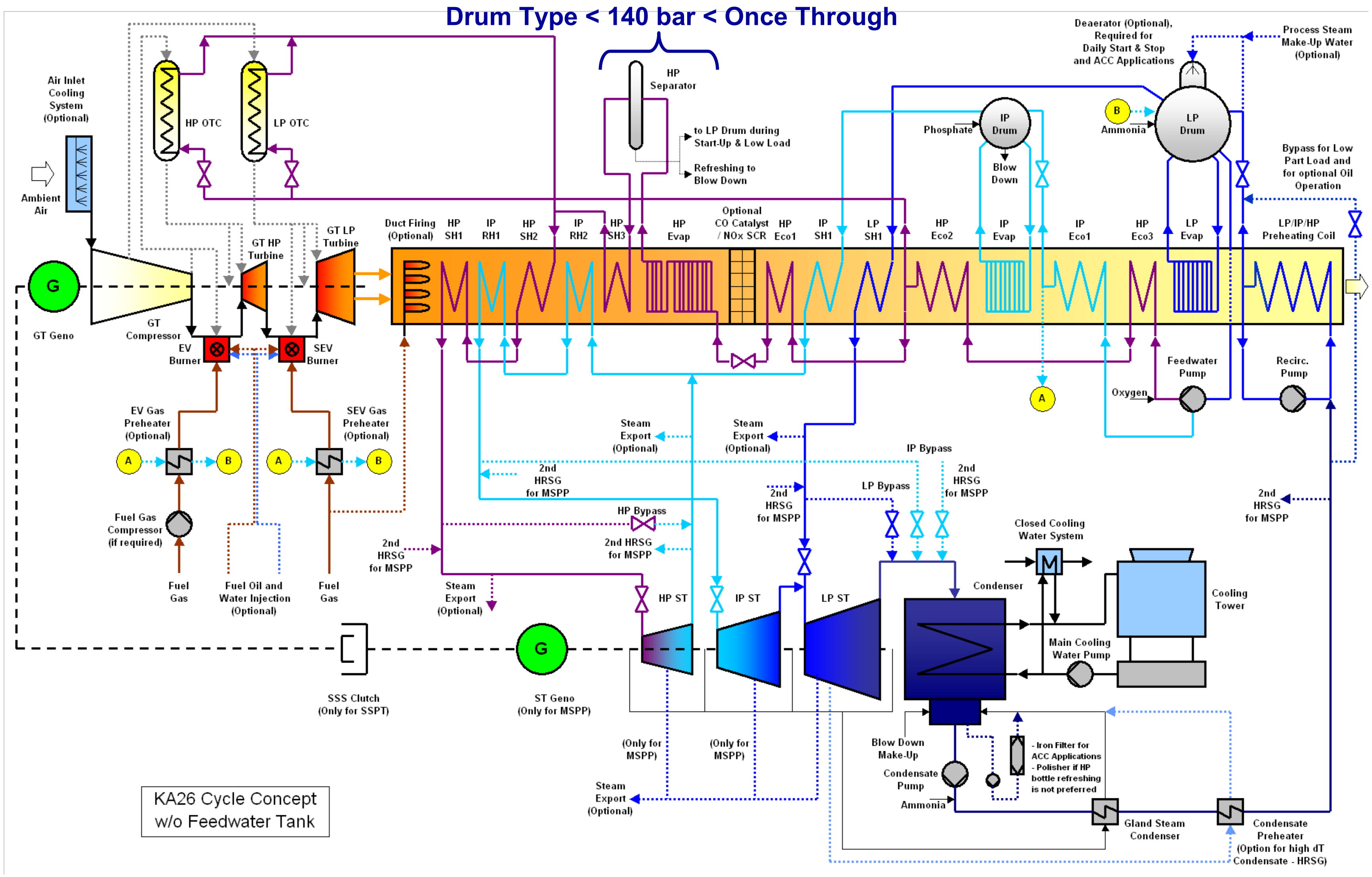
Combined Cycle Power Plants

3p-RH Concept w/o Feedwater Tank



Combined Cycle Power Plants

3p-RH Concept with Feedwater Tank

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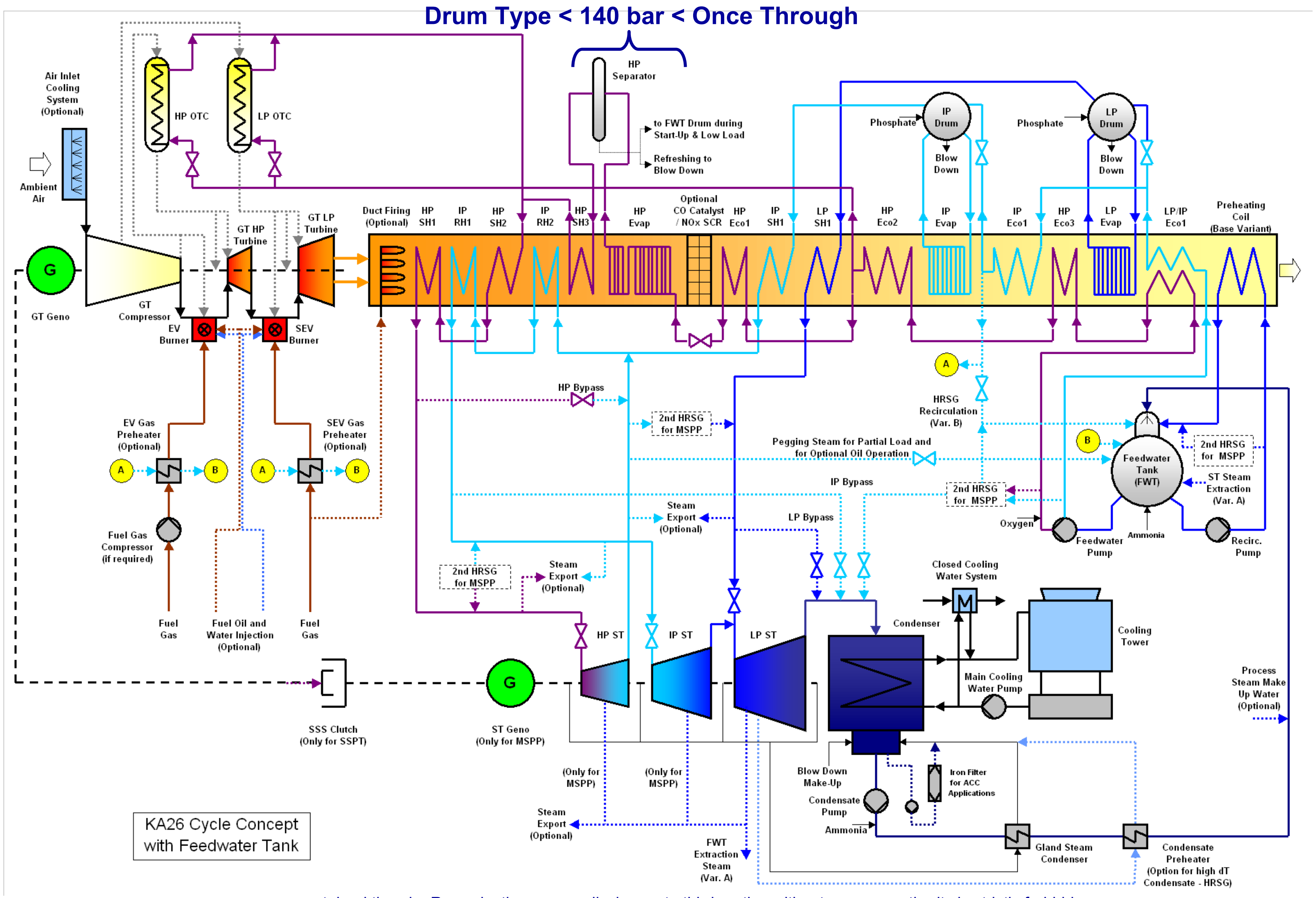

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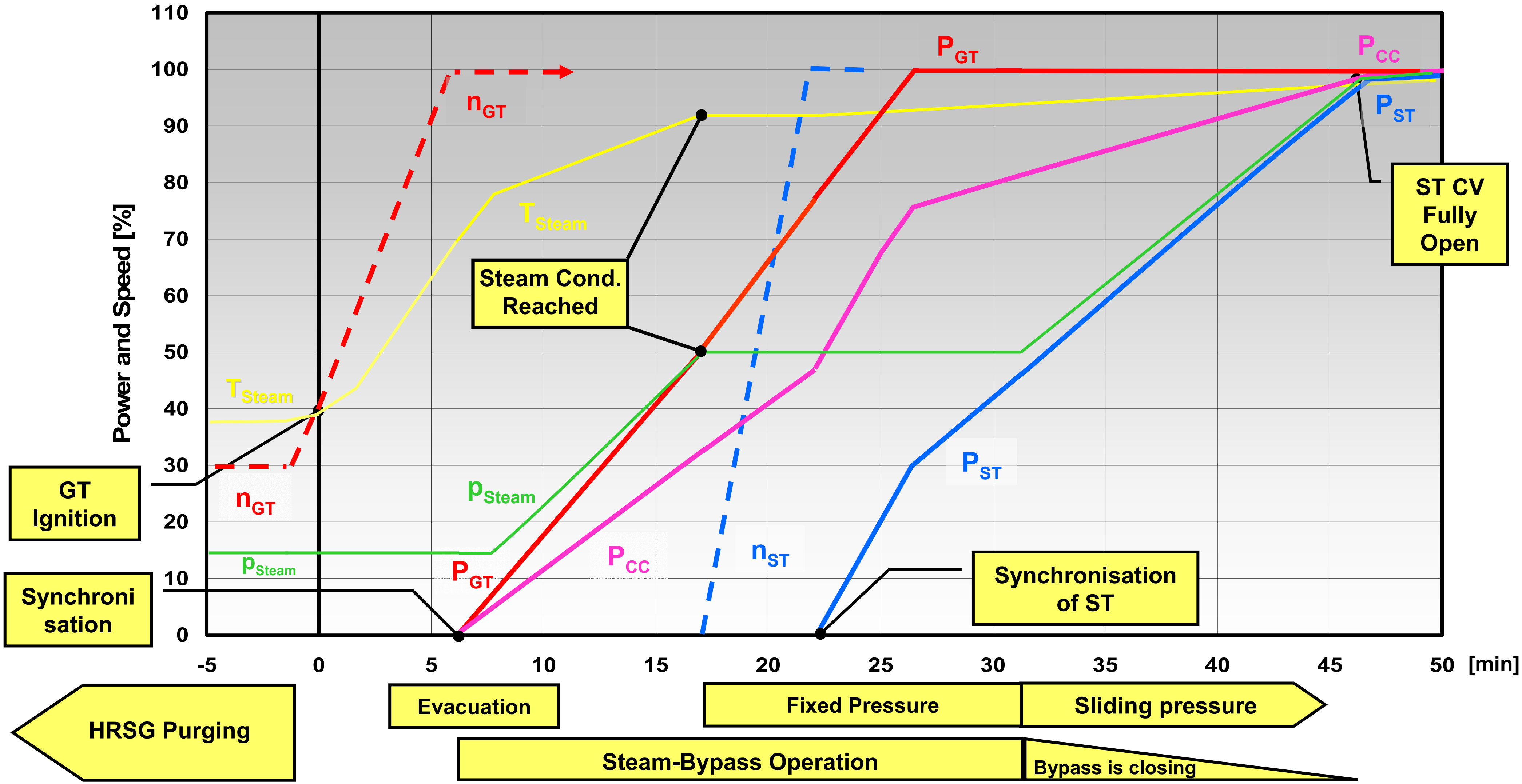
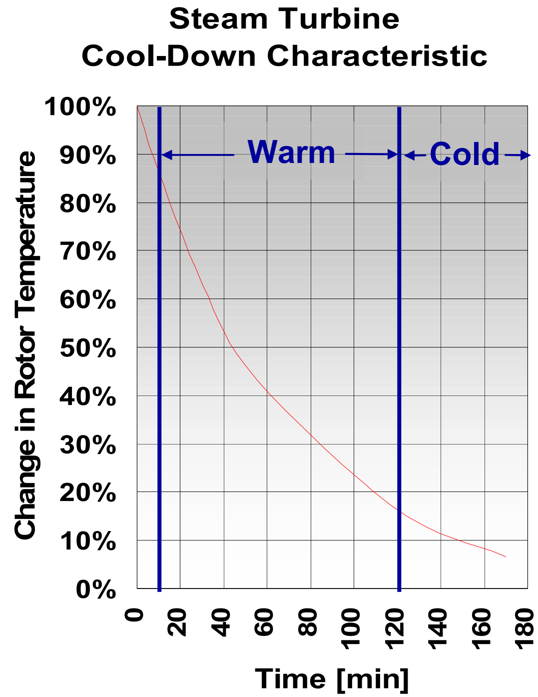
CCPP
Hot Start-Up (< 50 min)



Combined Cycle Power Plants
Warm and Cold Start-Up

- The stress limiter of the steam turbine defines the gradient of the acceleration and steam turbine loading
- The higher the nominal steam temperatures and the larger the steam turbine, the more moderate are the acceleration and loading gradients
- Major part of the warm-up is done at 50% steam turbine speed at low centrifugal forces
- During acceleration and warm-up of the steam turbine, the gas turbine is kept at a hold point of ~15% load (Fuel optimized concept)



- The ST rotor warm-up duration is depending on the individual stand-still (cool down) time. Typical start-up times (GT ignition to ST full load):
  - Shut-Down over the Weekend (52 hour shut-down)
    Warm-Start is completed after 110 - 150 min
  - Cold-Start is completed after 145 - 165 min (> 120 hours stand-still)

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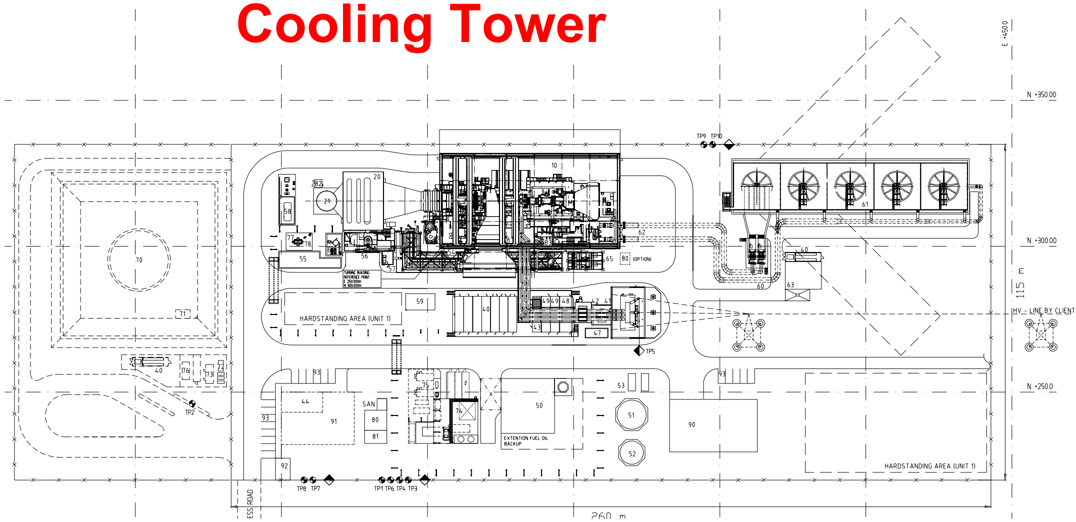
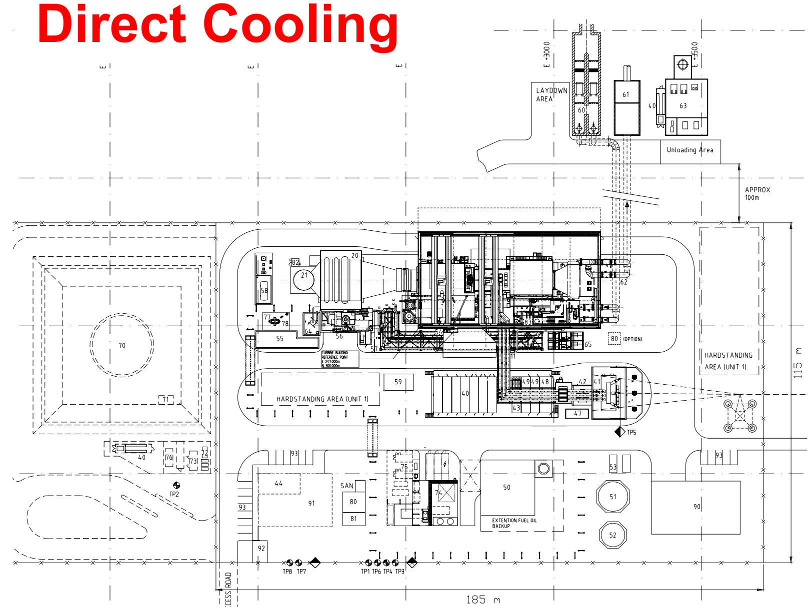
Combined Cycle Power Plants
Single-Shaft Site Layouts

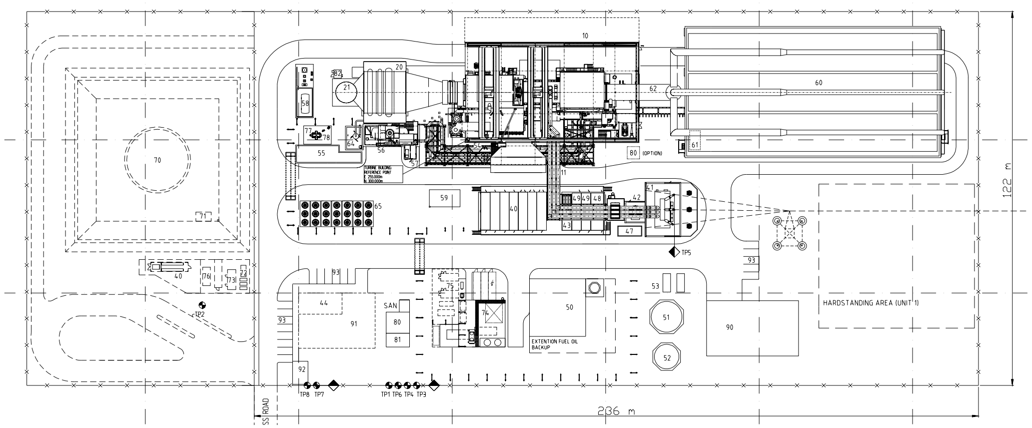
Cooling Tower



Direct Cooling



Air Cooled Condenser



Plant Sizes

(w/o Fuel Oil Storage and HY-Switchyard)

- Cooling Tower 260 x 115 m = 29’900 m2
- Direct Cooling 188 x 115 m = 21’620 m2
- Air Cooled Condenser 239 x 122 m = 29’158 m2

Combined Cycle Power Plants
Site Layout for Multiple SSPT Units

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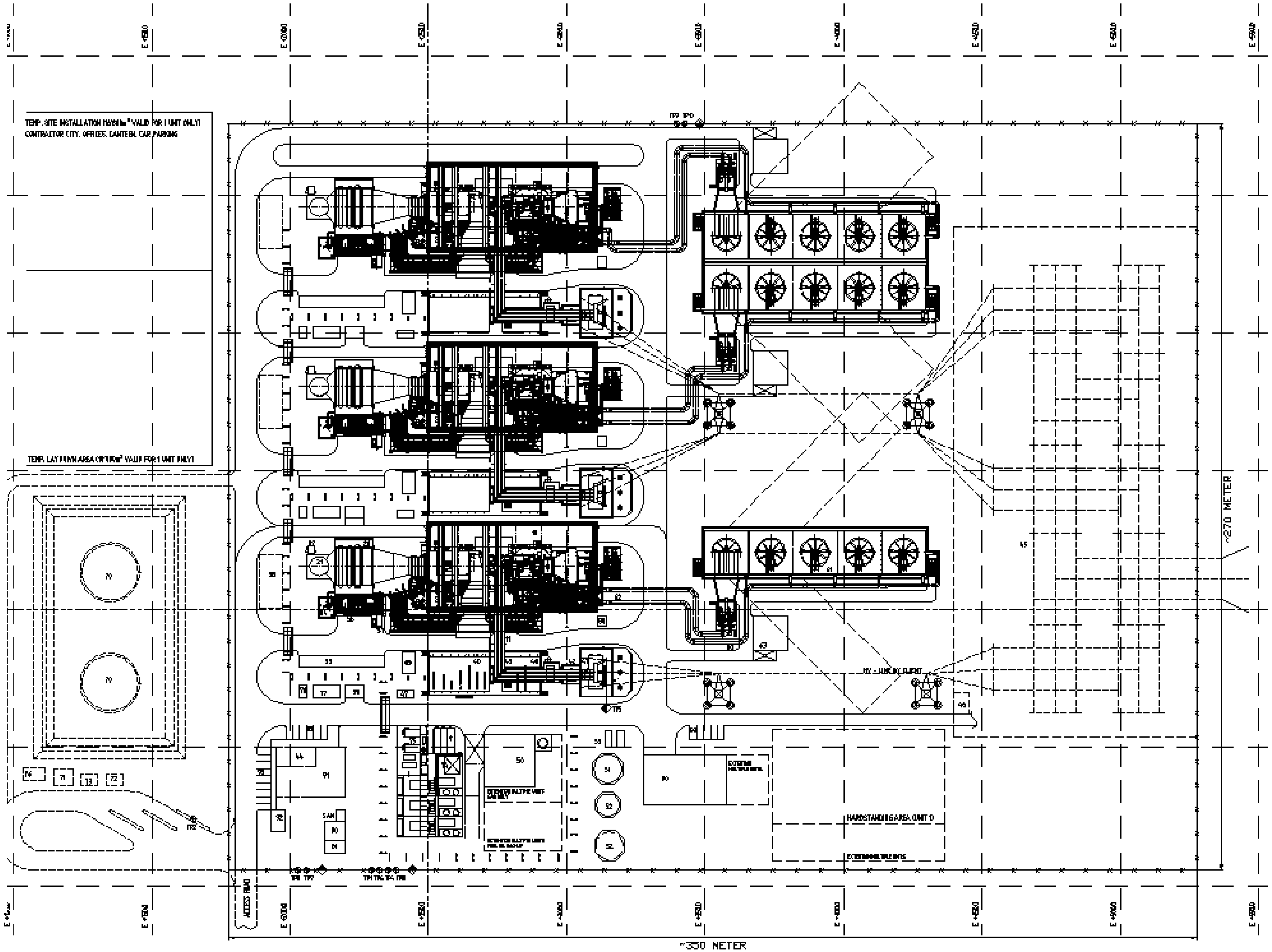
- Possibility of staged block installation with reserved extension areas for the Balance of Plant areas
- Optimized axe distance with minimized interference between the blocks results in a very compact design



Combined Cycle Power Plants
Multiple Multi-Shaft Units

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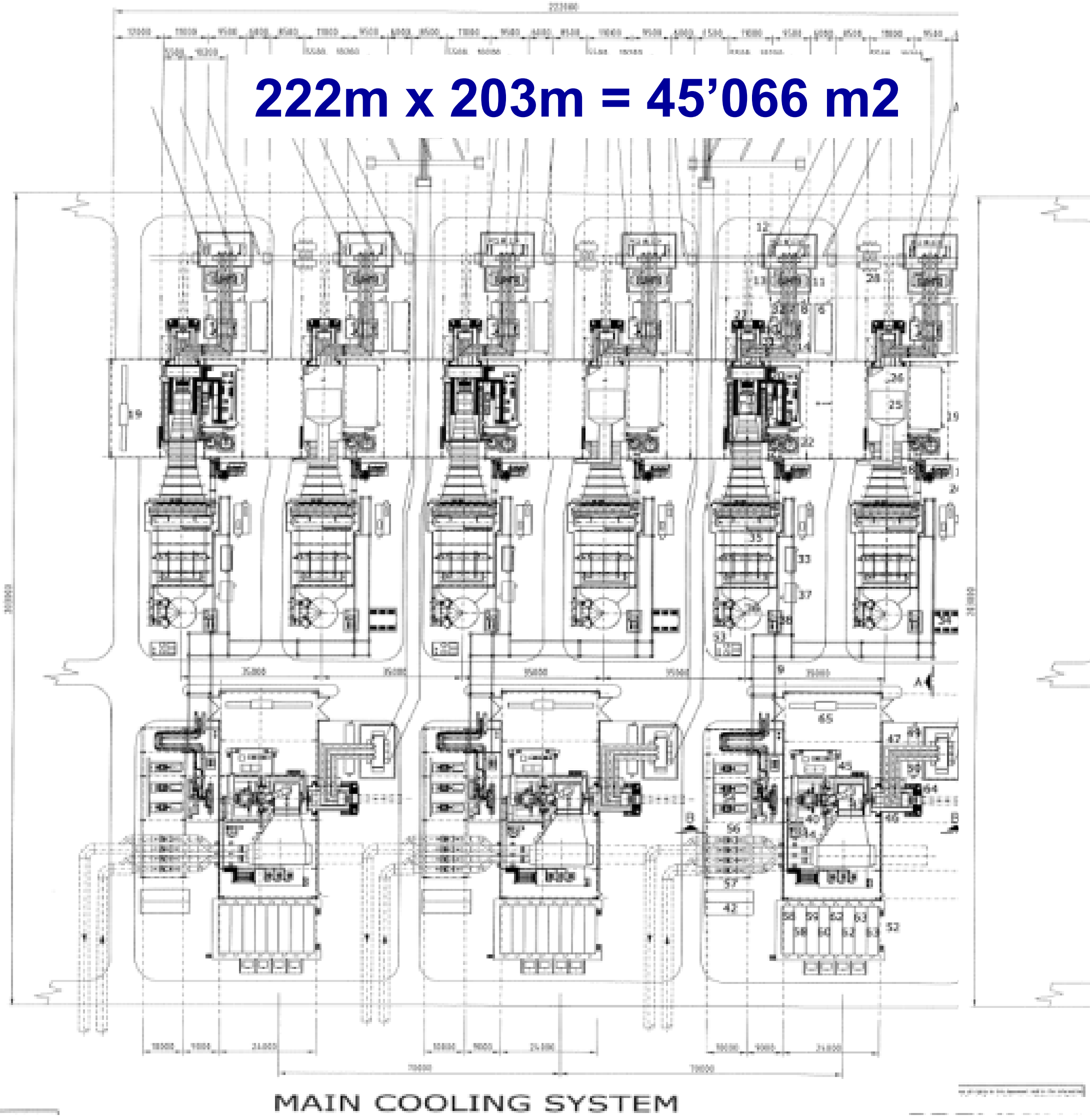

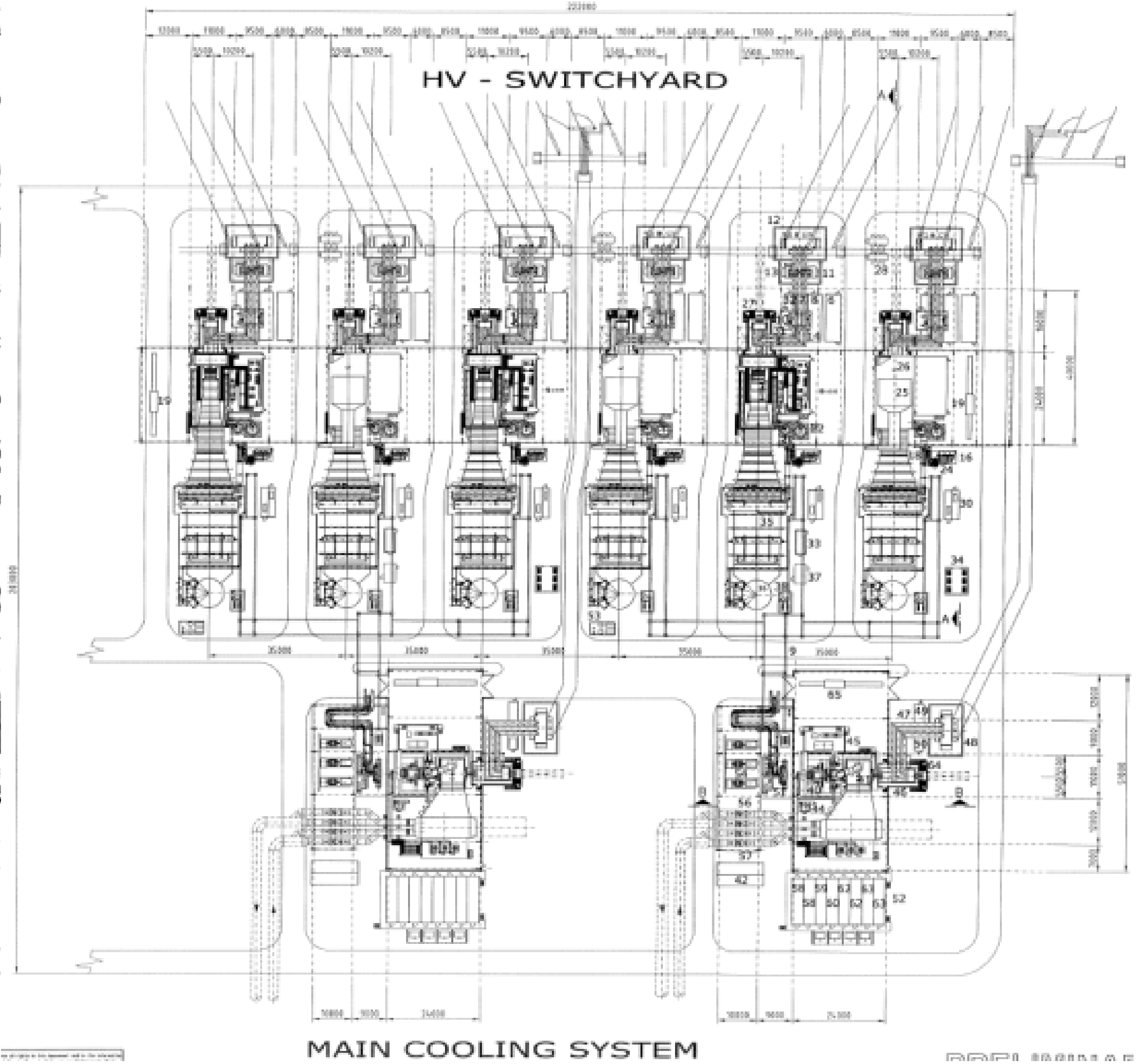

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Combined Cycle Power Plants
Perspectives

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- Larger plant sizes > 800 MW
- Net Efficiencies up to 60%
- Reduced required space (MW/m2)
- Shorter installation time through increased modularisation
- Shorter start-up times
- High optional power augmentation flexibility
- Lower emissions
- Longer inspection intervals

} **Lower Cost Of Electricity**

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