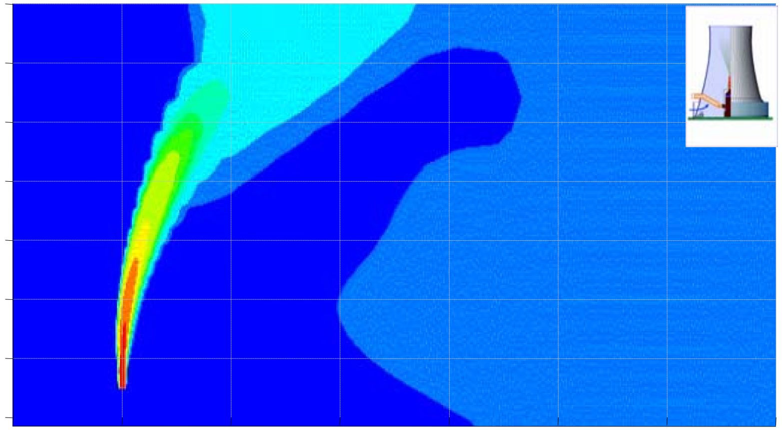
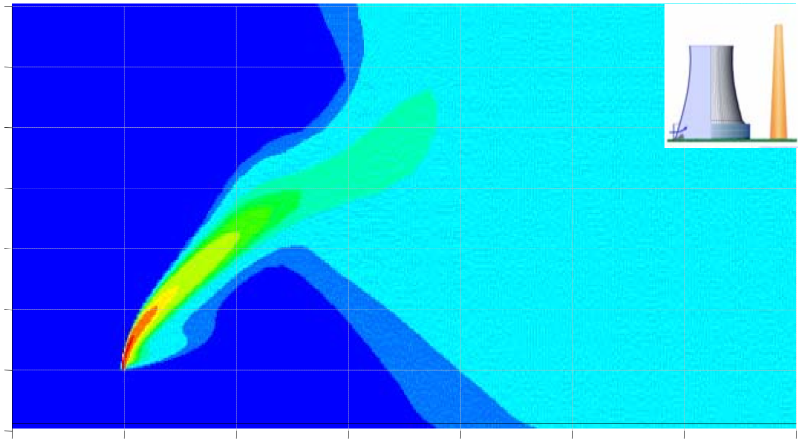
HELLER System: The Economical Substitute for Wet Cooling - *to avoid casting a shadow upon the sky*

by András Balogh, Zoltán Szabó

Paper for EPRI Workshop on
Advanced Thermal Electric Power Cooling Technologies
July 8-9, 2008, Charlotte (NC)





Thermal Engineering / **GEA EGI Contracting/Engineering Co. Ltd.**

Abstract

In view of shrinking fresh water resources, sinking water table level, polluted ground water and occasional severe droughts, generally there is a consensus about the importance of applying water conservation type cooling solutions. However, when making decision on cooling for a specific power project, even now water conservation is often regarded as a potential extra cost burden. Therefore, without an economic assessment, if license to use water can be received, wet cooling is selected. Water entitlement is often underpriced or a question of permission only. Against this ambivalent attitude it is claimed here, that a group of water saving cooling systems, the ***advanced version of the HELLER System*** *(an indirect dry cooling)* ***and its dry/wet derivatives*** *can be justifiable purely on economic bases against a wet cooling system even at a medium make-up water cost; thus providing the environmental advantages as an extra benefit.*

This paper introduces the system & component designs of the Heller Systems in general as well as their main features via project references. Among others it is shown how the natural draft Heller Systems provide a greener and cheaper opportunity for exhausting flue gases of coal fired power plants by applying the stack-in-tower or FGD-in-tower concept. The results of some case studies assessing cooling systems' economics are also presented, showing how a natural draft Heller System – if evaluated on lifecycle present value basis – can extend the economic viability of water conservation type cooling systems against wet cooling.

Contents

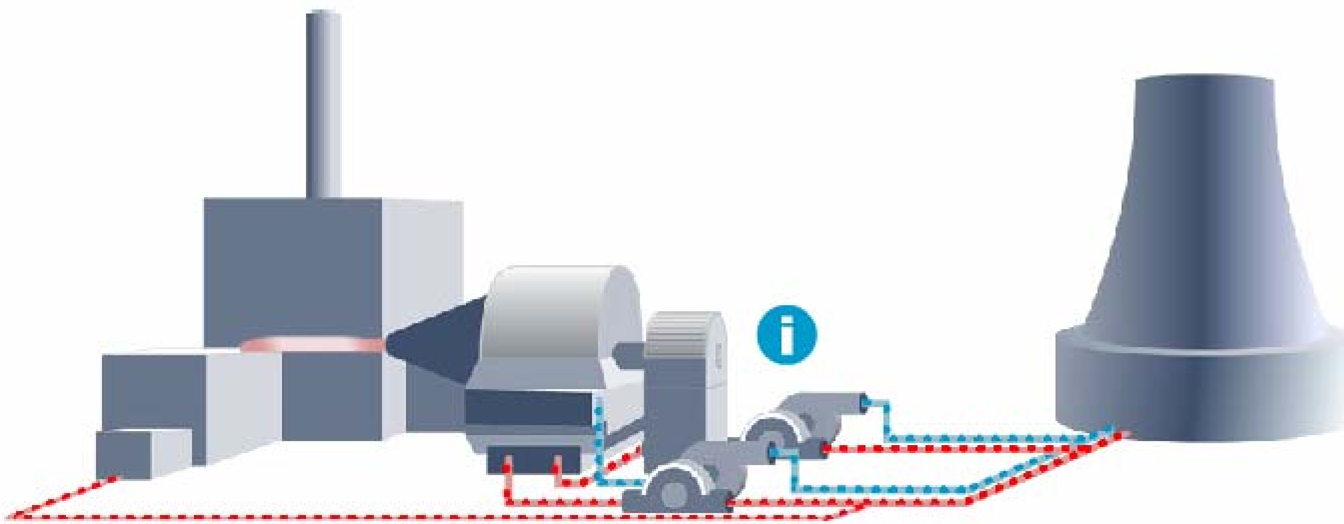
Page

1. What is the Advanced HELLER System & what is it for ?

1.1 The all-dry HELLER System

Heller System

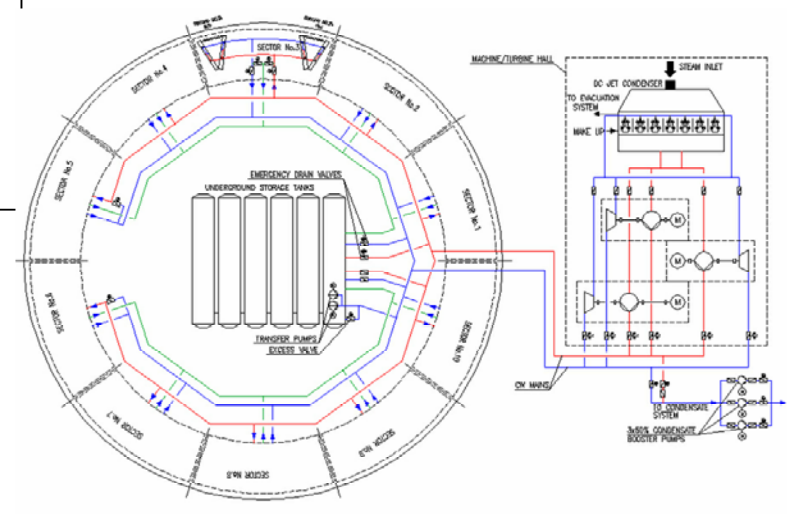
To continue your tour through our Heller System please press



HELLER System is an indirect dry cooling plant. The power plant waste heat is initially exchanged in a condenser (preferably a direct contact one) to a closed cooling water circuit. The heat absorbed by the water is rejected to ambient air in fin tube type heat exchangers. Air moving can be either by natural or mechanical draft.

© GEA Energy Technology GmbH

Flow diagram of HELLER System for a large supercritical unit



❖ **Features to notice**

▪ A completely closed and pressurized cooling circuit, where vacuum is limited to the small space of DC condenser.

▪ Sectionalized air cooler arrangement; easy & efficient online air cooler cleaning

▪ Air moving either by mechanical or natural draft

▪ The DC condenser and natural draft tower shell are practically maintenance-free with 100% availability.

▪ Mono-metal, all-aluminum air coolers for 40+ years life-span, withstanding external and internal corrosion; no flow accelerated corrosion (FAC); adequate for OT water chemistry

▪ The conventional condensate extraction pumps can be substituted by simple booster pumps

▪ Providing buffering condensate capacity as well as adequate conditions for CPP - including remaining within resin temperature limit (60 °C, i.e. 140 °F) even at max. ambient temperatures

▪ High thermal inertia countering negative effects of wind gusts

▪ The extra condensate volume in DC condenser hot-well allows primary frequency control of supercritical cycles by condensate throttling.

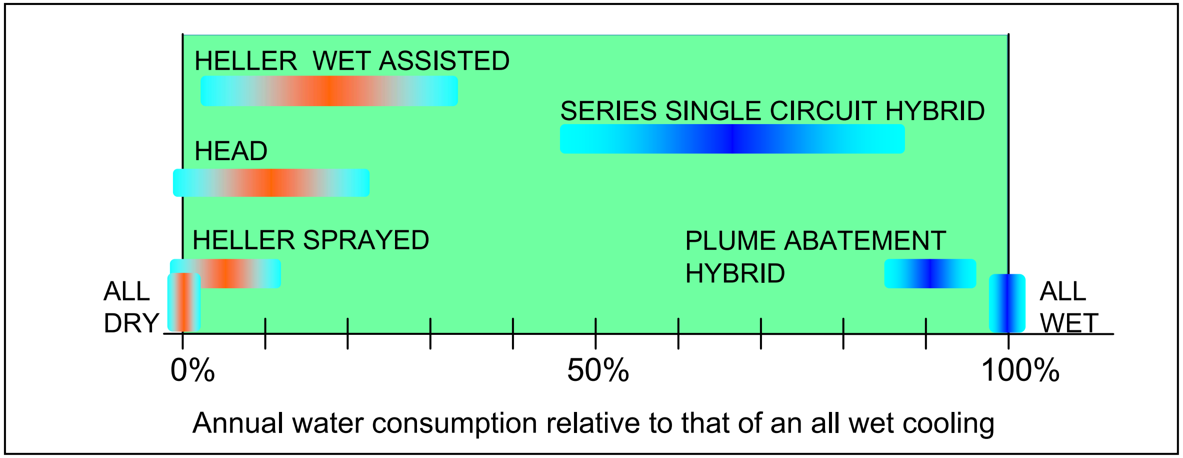
1.2 Dry/wet HELLER System derivatives

❖ **EGI has developed several cost effective dry/wet combinations derived from the all dry HELLER System aiming at:**

- improving environmental compatibility and water conservation feature relative to wet cooling
- improving summertime turbine output and if possible reducing investment costs relative to dry cooling

HELLER System is well suited to dry/wet combinations since at lower ambient temperatures it is capabile to establish even the same vacuum than a wet cooling (whereas a direct ACC part – due to the increased pressure loss of the increasing volumetric steam flow – can not even approach the same). Of course, the selected LP turbine choking point may limit this useful vacuum, hence comes the importance of summer wet assistance to allow to use a larger exhaust annulus area LP turbine without exceeding the maximum allowable back-pressure.

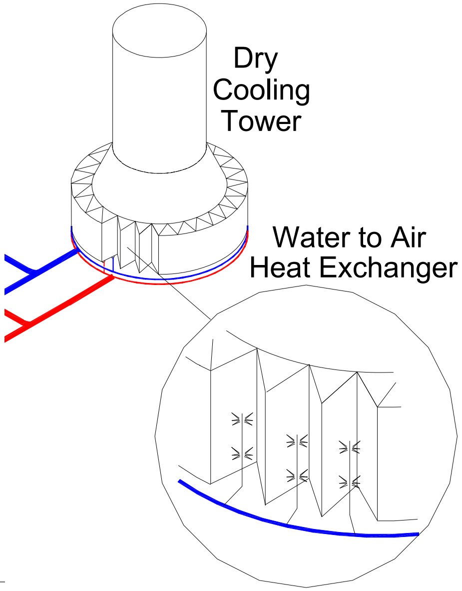
Water conservation features of different cooling systems are classified by their annual water consumption referred to an all wet cooling system.



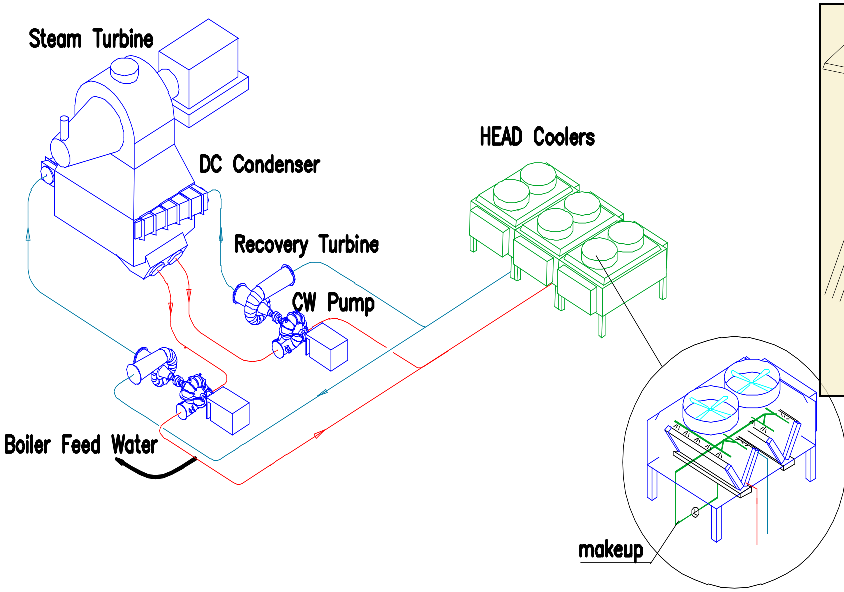
➢ Dry HELLER System with Supplemental Spraying (1-3%)

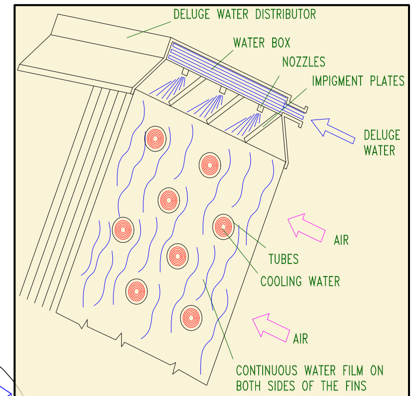
EGI has elaborated a special know-how to apply supplemental spraying in a technically and economically efficient way. Besides keeping time limit, providing adequate spraying water quality and using the right heat exchanger material & geometry, it is essential to apply spraying only to the coldest section of the air coolers.

Supplemental spraying is used for peak-shaving in the hottest summer days as well as improving plant availability at excessive conditions or in emergency cases. Also, it helps the optimum cold-end matching i.e. – allows to reduce max. allowable backpressure of the steam turbine.



➢ HEAD (Delugable) Cooling System (1-20%)



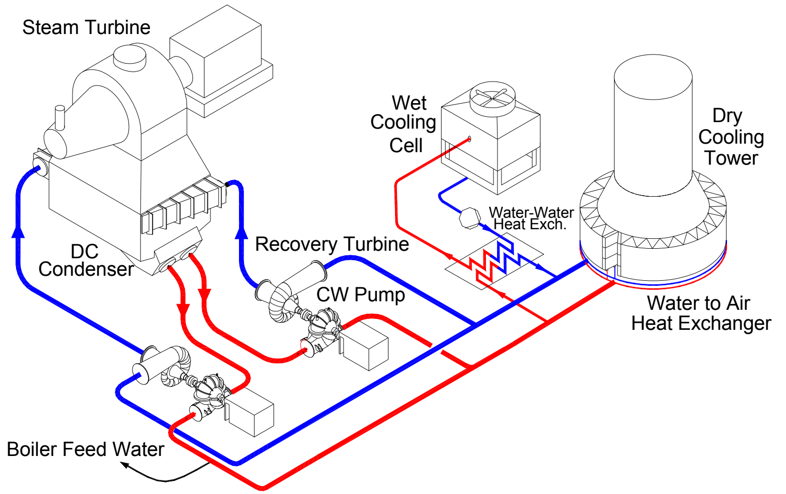


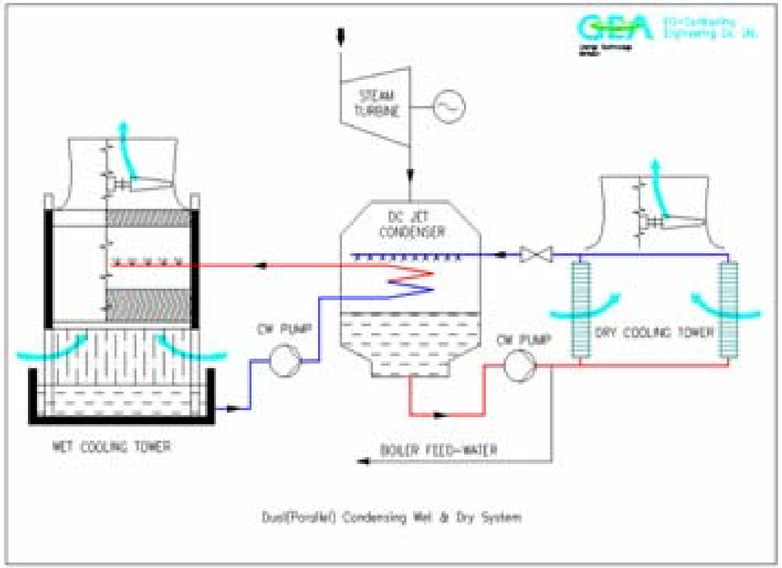
- A flexible solution to summer peaking power generators or co-generation plants with seasonally changing heat-load
- All dry operation through-out a significant part of the year
- A heat exchanger optimal for both dry & wet operation
- Parallel delugable peak coolers can advantageously be used for dry main cooling towers
- Also used for aux. coolers

Dry Tower with parallel delugable Peak Coolers (1-4%)

Completely Dry/deluged CS (10-20%)

➢ HELLER System with Assisting Wet Cells (5-40%)





• With an all dry HELLER System (natural or mechanical draft) assisting wet cells are connected either in parallel or in series to realize a wet assisted dry/wet cooling system (also can be applied to convert wet cooling to dry/wet one).

• The integration of the main dry & the assisting wet circuits can be via water-to-water heat exchangers as well as via the condenser (it may be a surface condenser with separate sections assigned to the dry and wet circuits; or preferably by applying together a DC jet condenser and a surface one).

• This group of solutions – applicable for any thermal power cycles – represents a special promise for nuclear power plants. It also can be applied to convert wet cooling to dry/wet one.

- The division between heat rejections by the dry and wet sections is characterizing the water conservation feature of the dry/wet cooling systems. It can be measured by the annual and maximum hourly water consumptions referred to those of the all wet systems.

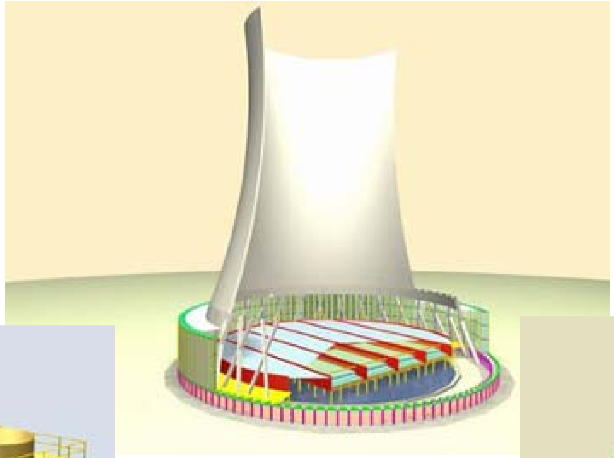
- The actual division of heat rejection - between certain limits - can be changed seasonally, daily and even hourly. The selection of the capacity ratio - either for the plant investment or for the operational schedule - depends on the make-up water availability & cost, the power demand & the electricity price as well as on investment and environmental costs & factors.

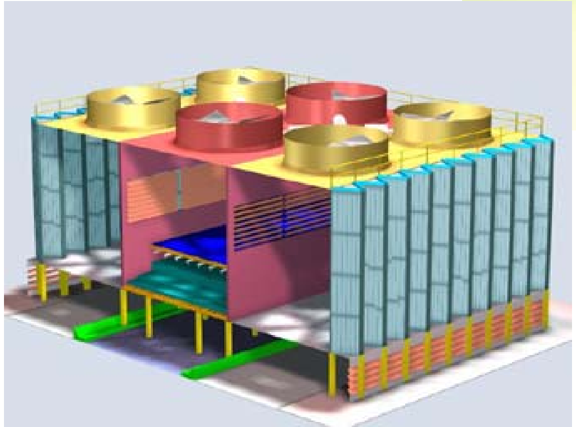
- There is a temptation to use 100% wet capacity in the hot summer days, however it not only would reduce the environmental value of the dry/wet system, but also would represent a rather high make-up water cost.

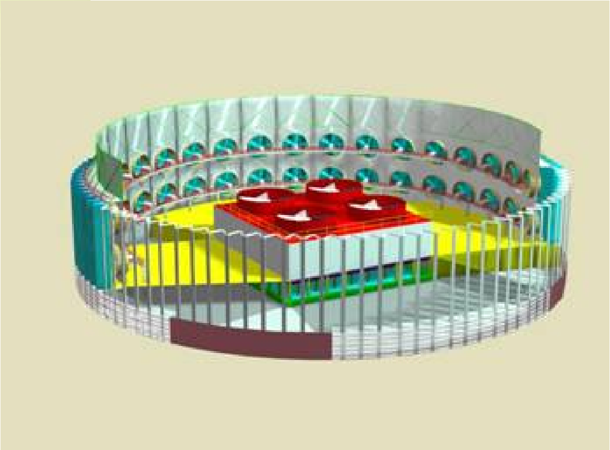
- Based on optimization and case studies, GEA EGI suggests to consider dry/wet systems in a broader range with 5-40% annual & 20-50% maximum water consumption, and with a **targeted range of 5-20% annual & 20-35% maximum water consumption.**

Wet cells assisting in parallel connection the natural draft HELLER System

• Wet assisted HELLER Systems have a variety of arrangement possibilities (wet cells separately outside of the dry tower or located within it, reducing noise and abating plume).







Conceptual designs for wet assisted HELLER Systems locating the assisting cells in the main dry cooling tower

2. Why and When to Consider the Advanced HELLER System?

➢ The decision for a cooling system has a lasting effect for 3-4 decades – throughout the whole life-span of the power plant

➢ To select the most promising cooling solution it is worthwhile to make a comprehensive evaluation based on economic life-cycle present value cost analysis.

➢ Regarding cooling systems as an integral part of the power cycle, their impact on the cost items of the complete power plant shall be investigated.

➢ GEA EGI has contributed to a number of comparative & comprehensive economic evaluations made mainly by power plant owners (some of those projects have been implemented since).

➢ Summarized results of two case studies are introduced herein evaluating and comparing cooling systems serving:

- a 800 MW_e combined cycle block considered for a European continental climate (average ambient temperature: 53.4 °F, ranging from 1 °F to 104 °F);
- a 900 MW_e supercritical coal fired power plant considered for a high elevation, rather warm site (average ambient temperature: 69 °F, ranging from 32 °F to 102 °F);

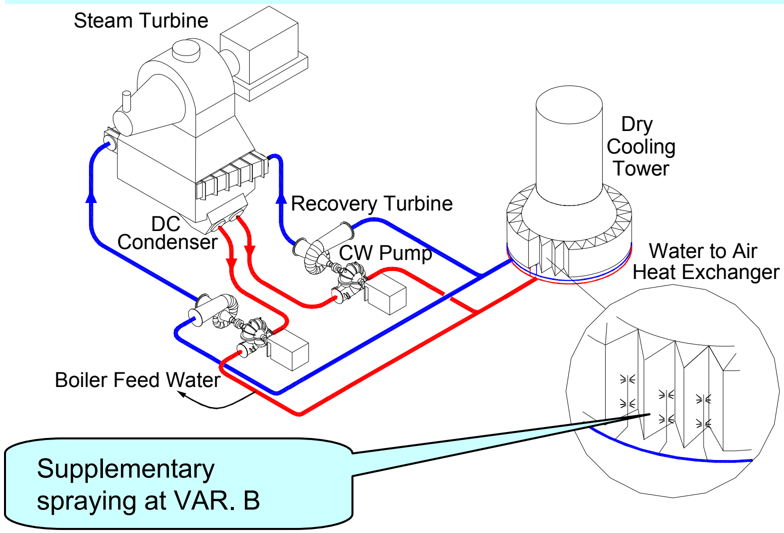
2.1 Results of cooling systems' evaluation serving a 800 MW$_e$ CCPP

800 MW CCPP.ppt

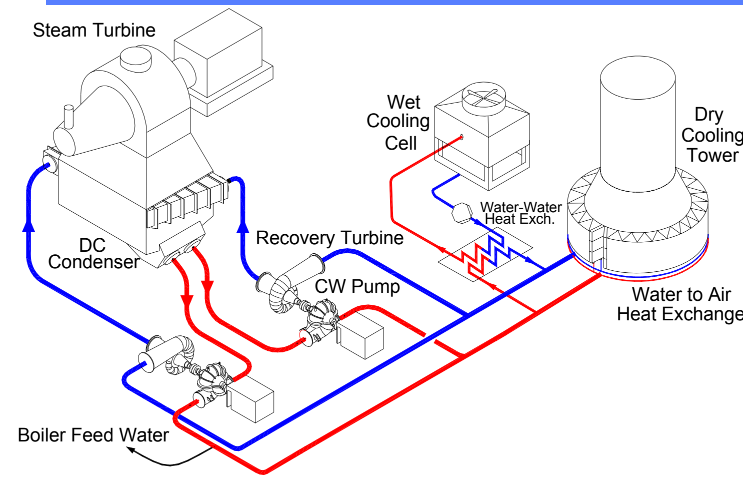
❖ Investigated variants:

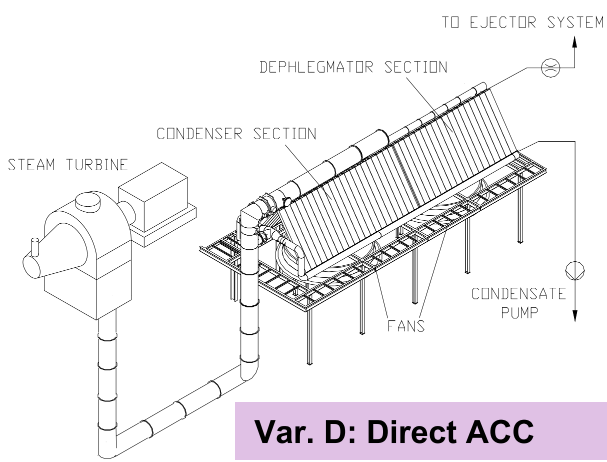
Var. A: HELLER System all-dry &

Var.B: HELLER System with Supplemental Spraying

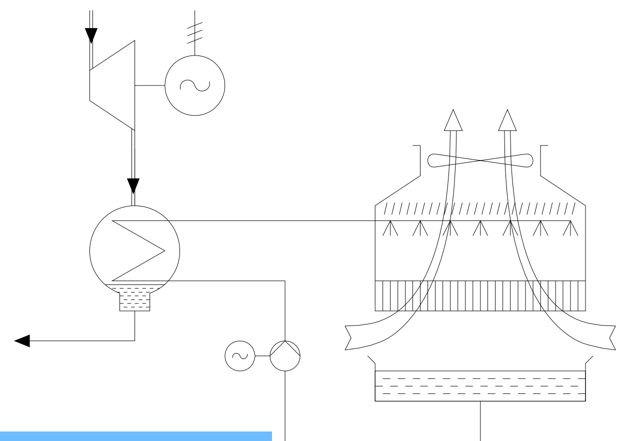


Var.C.: HELLER System with Assisting Wet Cells





Var. D: Direct ACC



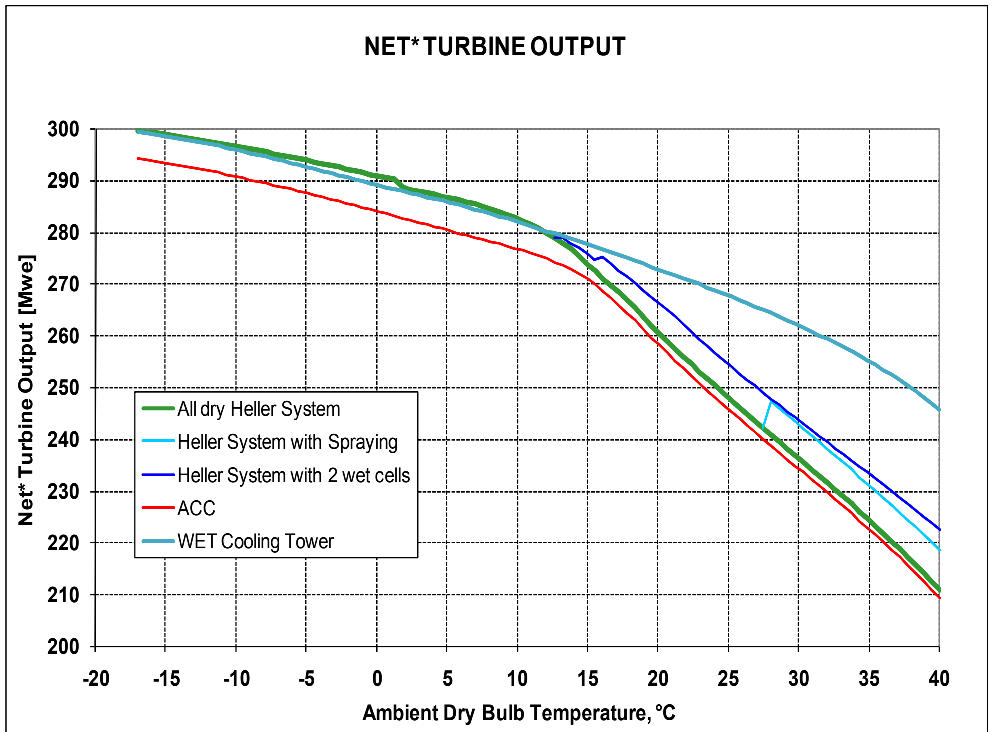
Var. E: Wet cooling

❖ Thermal & environmental aspects

- The power cycle equipped with an all-dry HELLER System generates 1.56% more electricity on year-round basis than the same unit equipped with direct ACC.
  It corresponds to the same percentage reduction in pollutant emission (SO_2, NO_x, CO_2) in case of equal electricity production.

- Compared to the wet cooling, the annual electricity with dry HELLER is smaller by 2.3%, which is reduced to 1.3% with a wet assisted HELLER System on cost of only 8.5% annual water consumption referred to that of all wet system.

Year-round Technical Results (7008 h/year)	VAR A HELLER dry	VAR B HELLER sprayed	VAR C HELLER Wet assisted	VAR D Direct ACC	VAR E Wet cooling
Annual „Net"* Electricity Generation (GW_eh /year)	1911.324	1914.442	1930.045	1881.921	1956.283
Average „Net"* Output (MW_e)	272.73	273.18	275.41	268.54	279.15

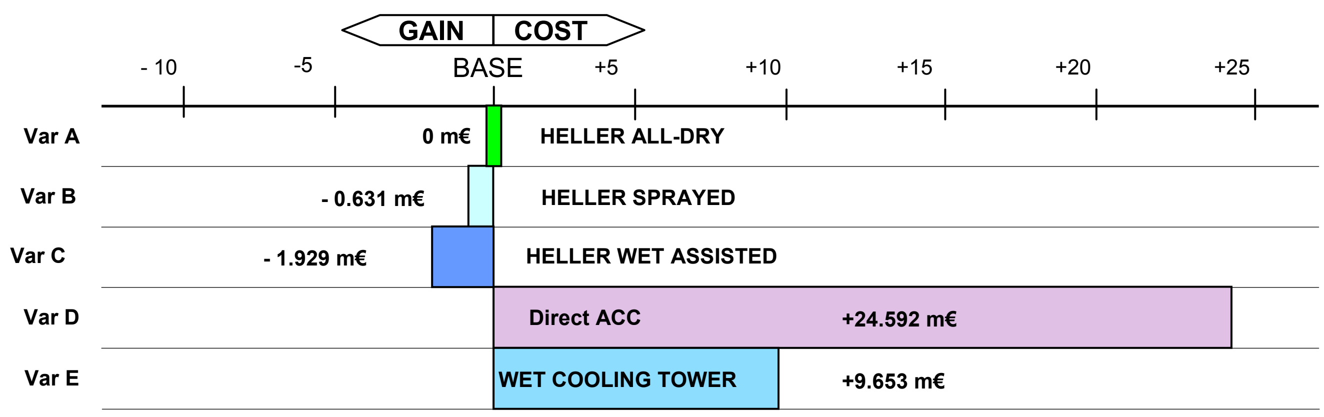


❖ Economical aspects

➢ Results of present value based life cycle economic assessment reflect a remarkable cost reduction by HELLER System and its dry/wet derivatives compared to wet cooling (at actual water & electricity prices: 0.6 €/m³ & 42 €/MWh); relative to direct ACC, there are even more massive cost savings.

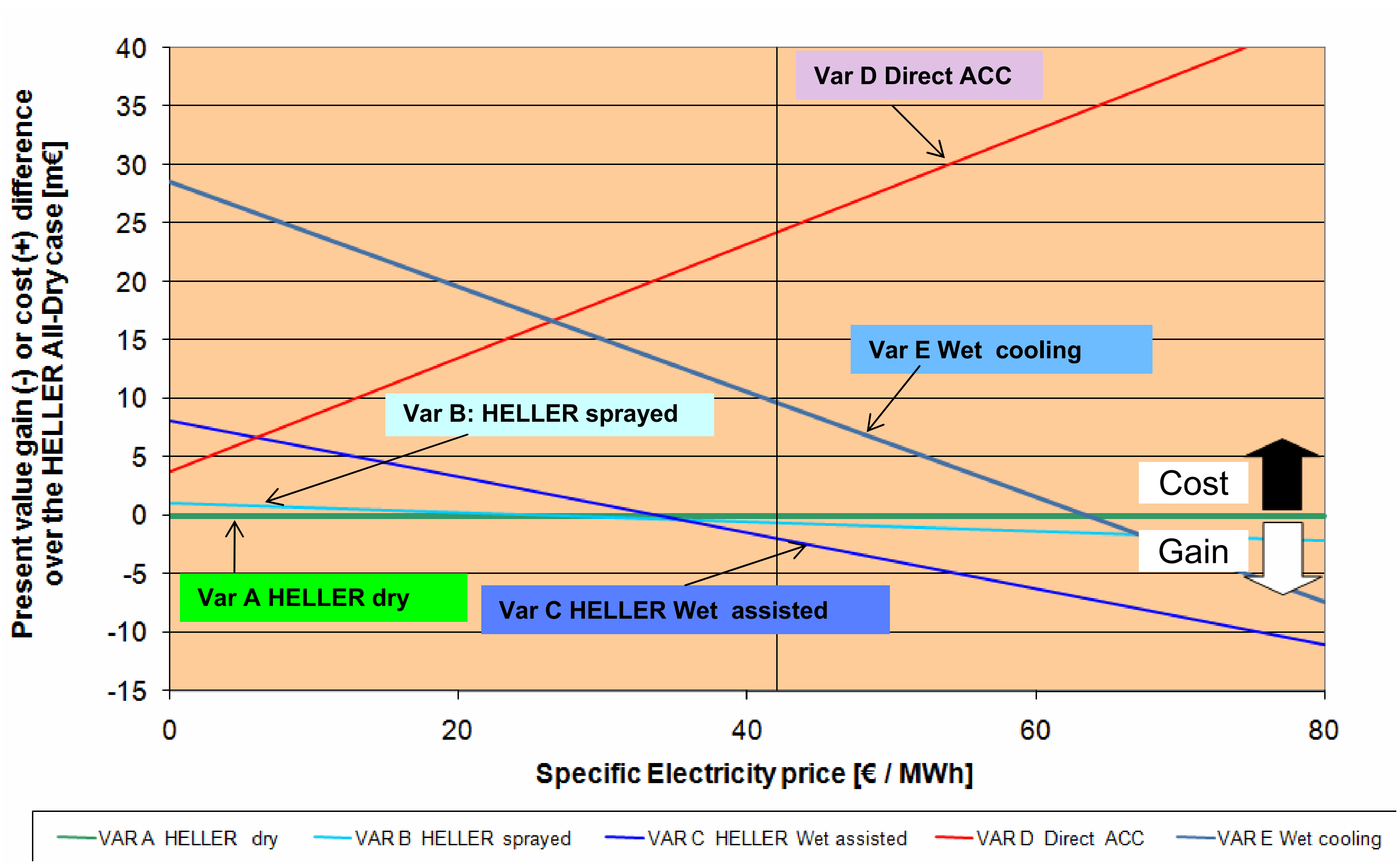
VAR. A	VAR. B	VAR. C	VAR. D	VAR E
HELLER All-dry	HELLER Sprayed	HELLER wet assisted	Direct ACC	WET COOLING TOWER
BASE	-0.631 m€ (gain)	-1.929 m€ (gain)	+24.592 m € (cost)	+9.653 m € (cost)

PRESENT VALUE BASED COST DIFFERENCES
(referred to the HELLER All-dry Cooling System)



❖ Economical aspects – cont.

➢ Variation of present value cost / gain differences in function of electricity selling price confirm the superority of HELLER Systems for the whole practical range of the electricity price (at the assumed make-up water price: 0.6 €/m³.

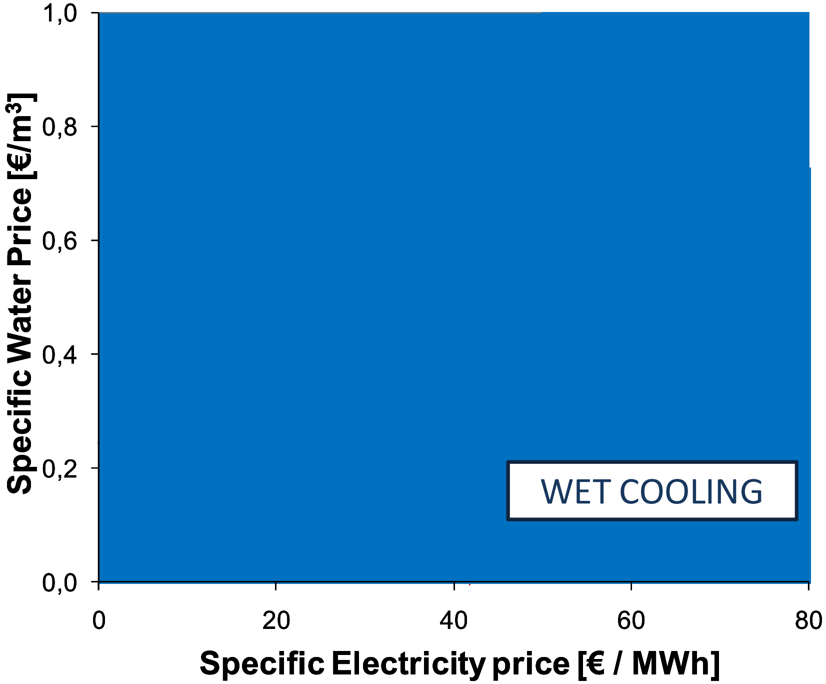


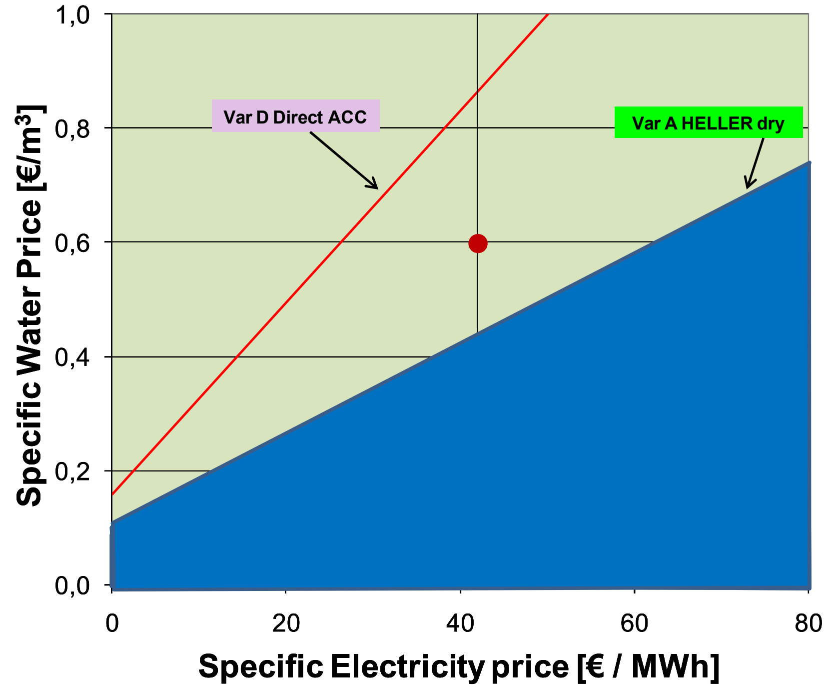
2.1 Results of cooling systems' evaluation serving a 800 MW_e CCPP – cont.

❖ Economical aspects – cont.

Economic viability envelopes

- coordinates of two vital factors: water and electricity prices – helps to judge financial stability of cooling systems relative to wet cooling in view of potential changes of these factors





➢ The all-dry HELLER System (var. A) is competitive against wet cooling (var. E) - at an assumed water price of 0.6 €/m^3 – up to 63.5 €/MWh electricity selling price.

➢ At the same electricity selling price (63.5 €/MWh) the wet assisted HELLER System (var.C) reaches economic equivalence already at 0.46 €/m^3 make-up water price.

2.2 Results of cooling systems' evaluation serving a 900 MW$_e$ coal fired supercritical cycle

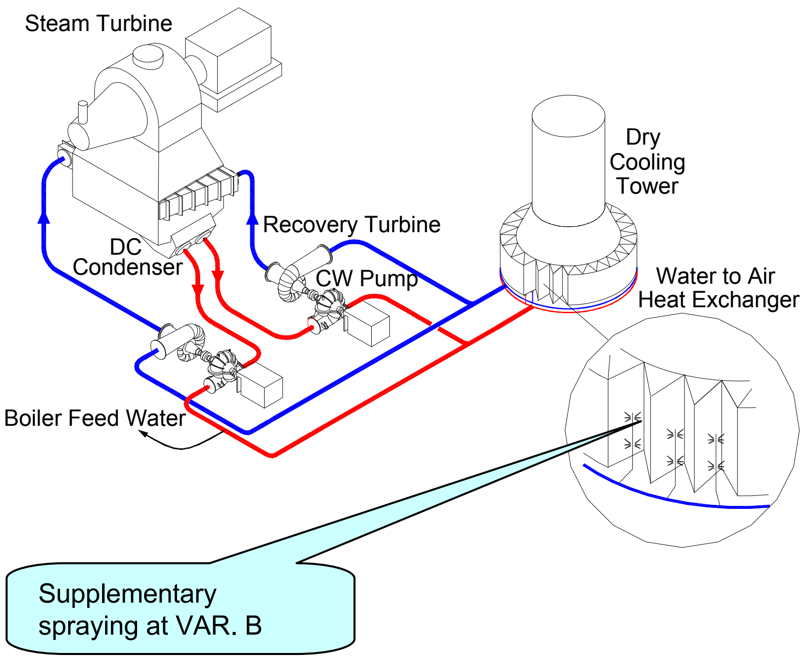
900 MW SC PS.ppt

❖ Investigated variants:

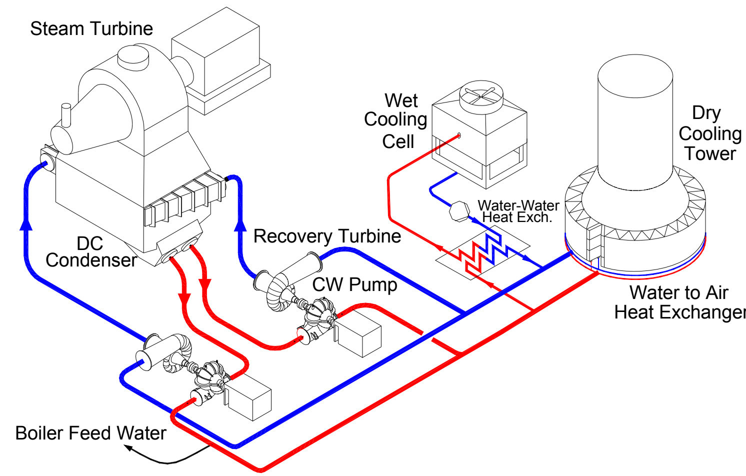
Variant A: HELLER System all-dry

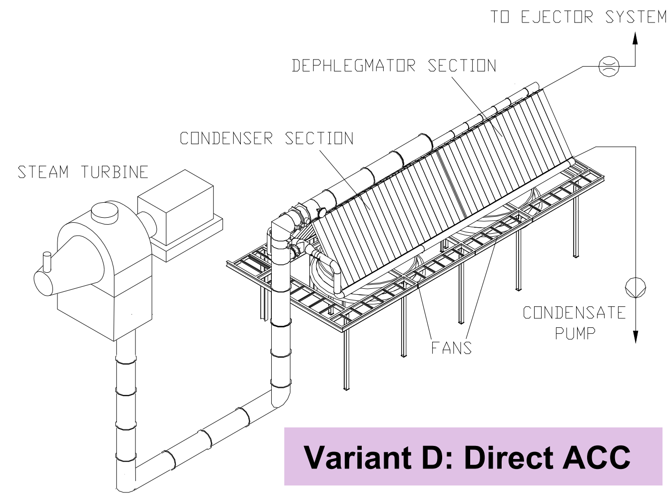
&

Variant B: HELLER System with Supplemental Spraying



Variant C.: HELLER System with Assisting Wet Cells





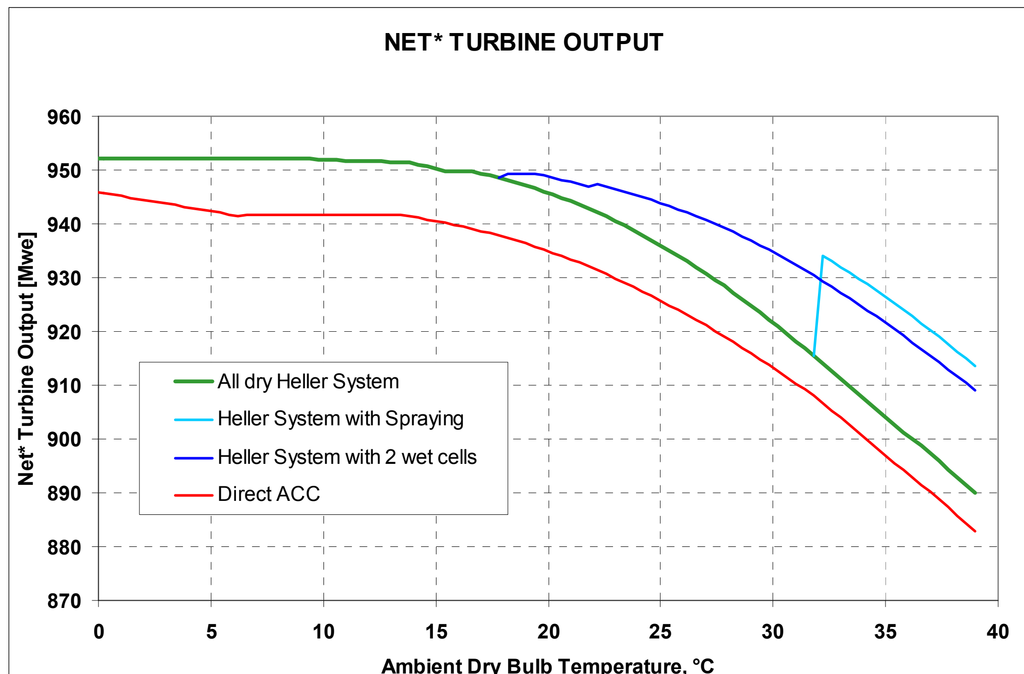
Variant D: Direct ACC

❖ Thermal aspect

- The power cycle equipped with an all-dry HELLER System generates 1.08 % more electricity on year-round basis than the same unit equipped with direct ACC.

Note:
This difference in efficiency could be measurably higher in areas of less warm climate and applying turbine with larger LP exhaust area.

Year-round Technical Results (load factor 0.9 (=7884 h/year)	VAR A HELLER dry	VAR B HELLER sprayed	VAR C HELLER Wet assisted	VAR D Direct ACC
Annual „Net"* Electricity Generation (GW_eh /year)	7426.703	7431.418	7457.817	7347.232
Average „Net"* Output (MW_e)	942.0	942.59	945.94	931.92



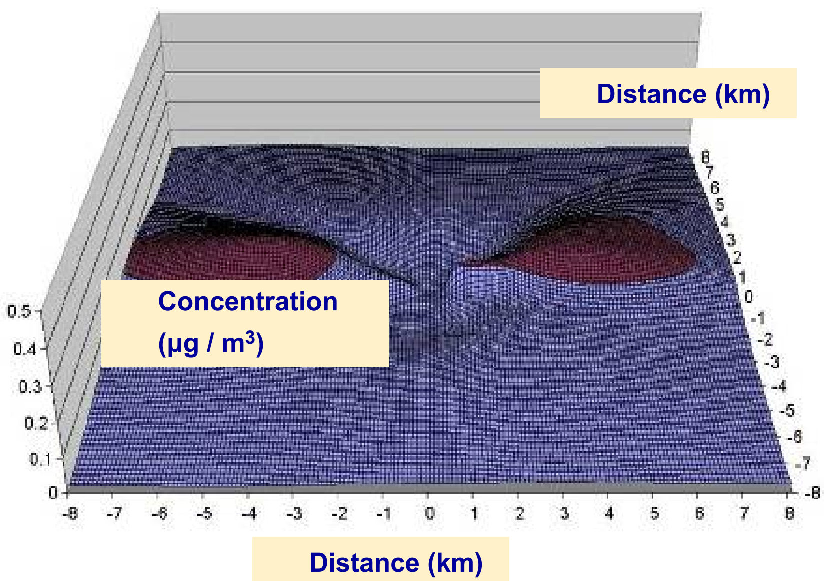
❖ Environmental aspect

- In line with the thermal efficiency improvement of the unit equipped with HELLER System compared to that of equipped with direct ACC, the emission of CO_2 and such flue gas pollutants like SO_2 and NO_X can be reduced by 1.08 %.

- The ground level concentration of pollutants (SO_2 and NO_X) can dramatically be reduced by applying HELLER System based on the stack-in-tower solution. *The charts herein show the yearly average SO_2 concentration for a similar project (2×800 MW_e SC units) for the plant equipped with HELLER System and applying stack-in-tower and the plant with direct ACC applying standalone chimney.*

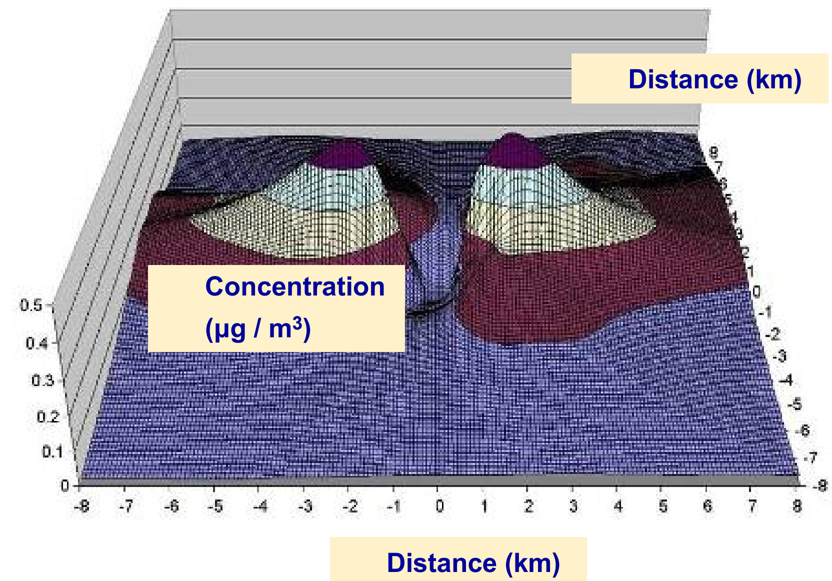
Yearly avegare SO_2

HELLER System with stack-in-tower



Yearly average SO_2

Direct ACC and 250 m standalone chimney



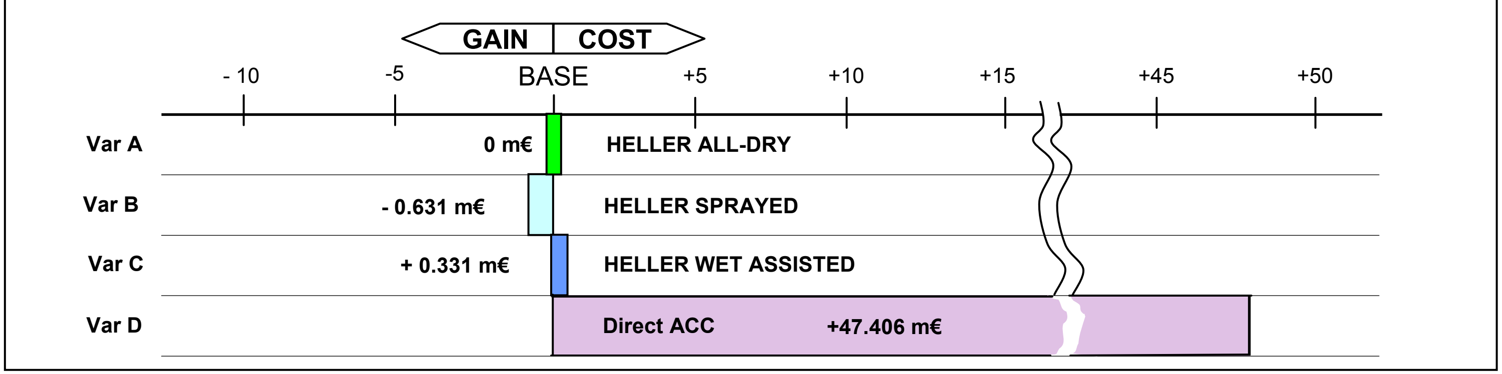
❖ Economical aspect

➢ Applying HELLER System results in a massive reduction of present value costs (at the actual electricity price: 35 €/MWh), while the capital cost of it and that of a direct ACC are very close to each other.

For coal fired power plants the capital cost of the natural draft HELLER System even can be lower than that of a mechanical draft direct ACC due to crediting it by the savings from stack-in-tower solution.

VAR. A	VAR. B	VAR. C	VAR. D
HELLER All-dry	HELLER Sprayed	HELLER wet assisted	Direct ACC
BASE	-0.637 m€ (gain)	+0.331 m€ (cost)	+47.406 m € (cost)

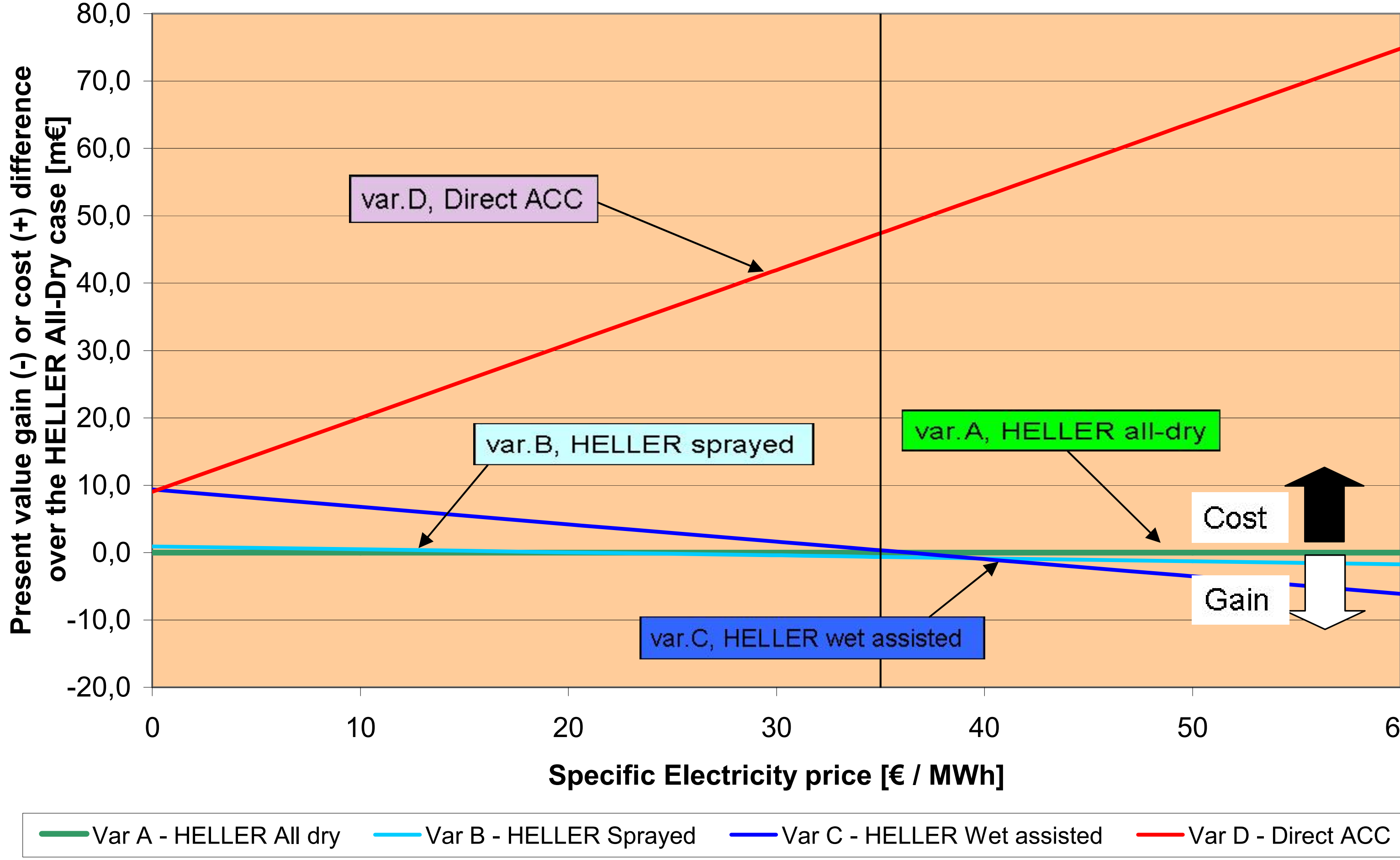
PRESENT VALUE BASED COST DIFFERENCES
(referred to the HELLER All-dry Cooling System)



2.2 Results of cooling systems' evaluation serving a 900 MW_e coal fired supercritical cycle – cont.

❖ Economical aspect – cont.

➢ The sound advantage of HELLER System over the direct ACC remains valid for any realistic specific electricity selling price as shown by this sensitivity chart:



3. Concepts Embodied: Reference Plants for All Seasons

- **More than 55 years of experience**
- **A total of 24,000 MW_e power plant capacity in service and under construction with the HELLER System**
- **EGI has reference plants in 20 countries including:**
  - ♦ units operating under extreme ambient conditions: *air temperature as cold as -62°C (-79.6°F) or as hot as +50°C (+122°F) (incl. areas over the arctic belt and desertous ones) and sites located at sea shore or at high altitudes (up to 6000 ft)*
  - ♦ the largest dry cooled Combined Cycle Plant in the world
  - ♦ the only dry-cooled nuclear power plant in the world
  - ♦ natural draft dry cooling towers through which flue gases are exhausted
  - ♦ cost efficient, environmentally compatible dry/wet derivatives of HELLER System: *770 MW_e equipped with supplemental spraying and 4300 MW_e with parallel wet assisting or delugable cooler cells*

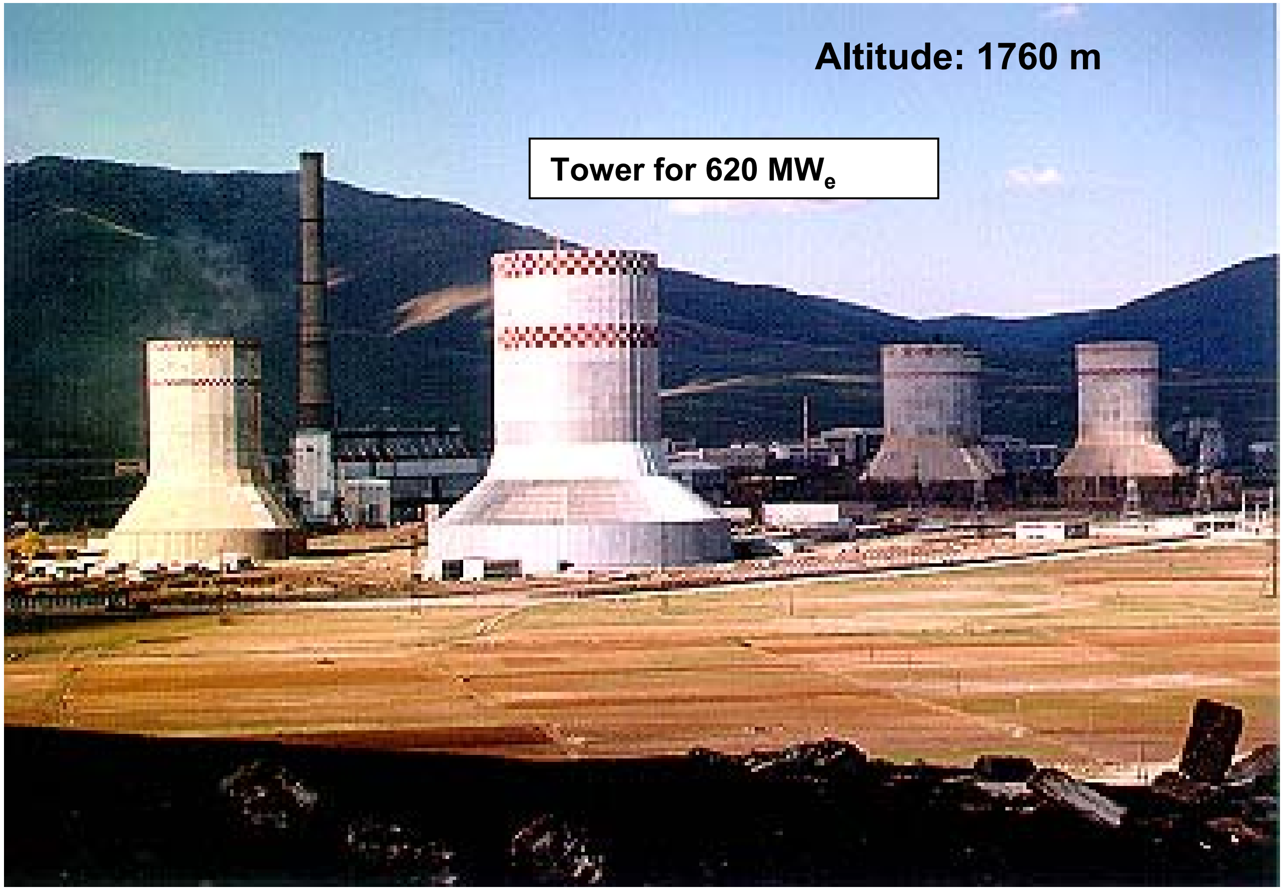
The 1st larger PS with HELLER

120 MW_e coal fired unit of Rugeley „A" PS, Great Britain

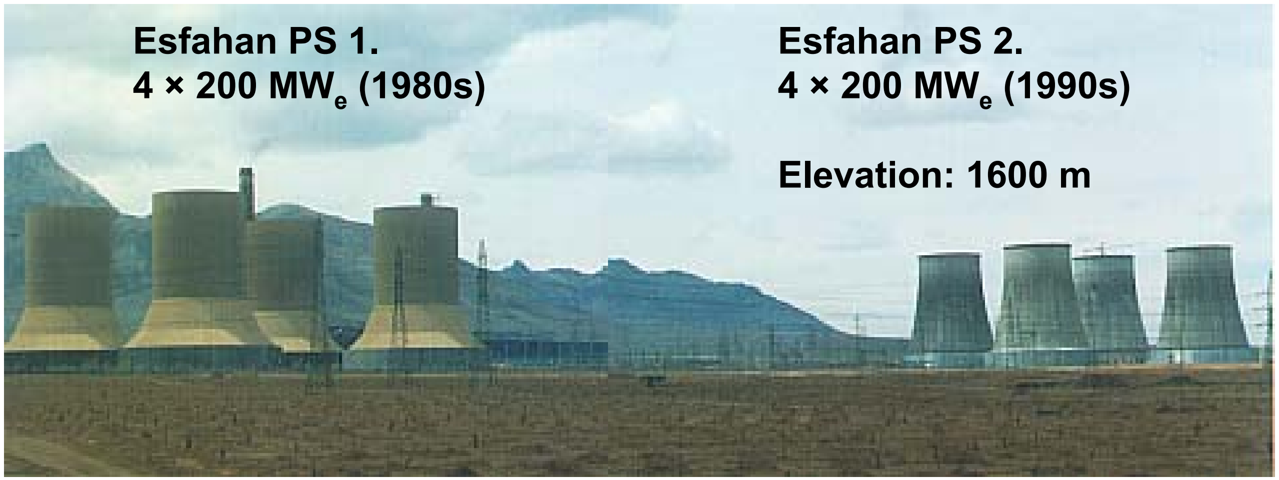
Commissioned: 1962 – Decommissioned: 1996

Armenia: High altitude & seismicity

In the background: towers of the original plant for 4 x 200 MW_e built in the 1970s
In the foreground: cooling tower to serve 620 MW_e supercritical extension (mid 1990)



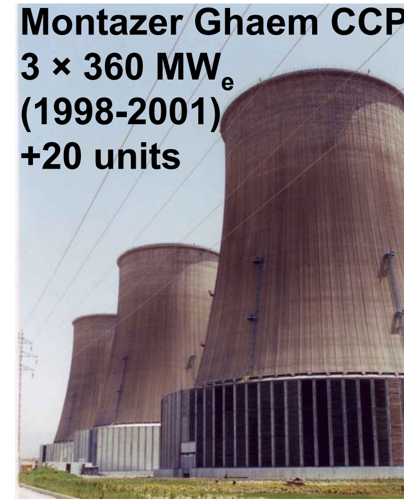
Iran: hot & cold & high sites



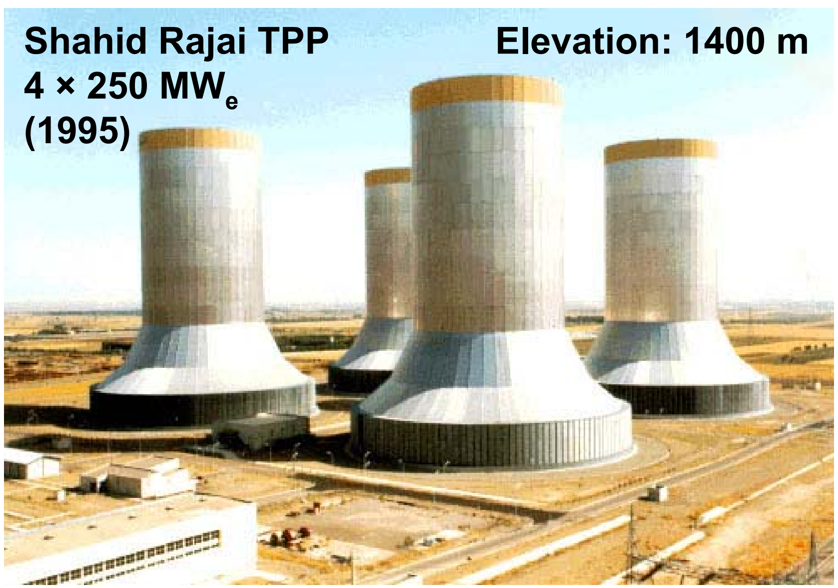
Esfahan PS 1.
4 × 200 MW_e (1980s)

Esfahan PS 2.
4 × 200 MW_e (1990s)

Elevation: 1600 m



Montazer Ghaem CCPP
3 × 360 MW_e
(1998-2001)
+20 units

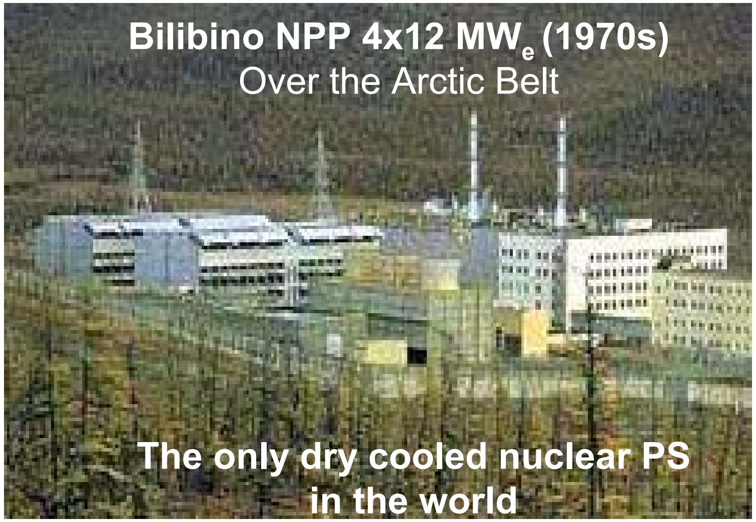


Shahid Rajai TPP
4 × 250 MW_e
(1995)

Elevation: 1400 m

Arak Ps 4 × 325 MW_e (1998-2002)
Elevation: 2000 m

Russia: frosty winter



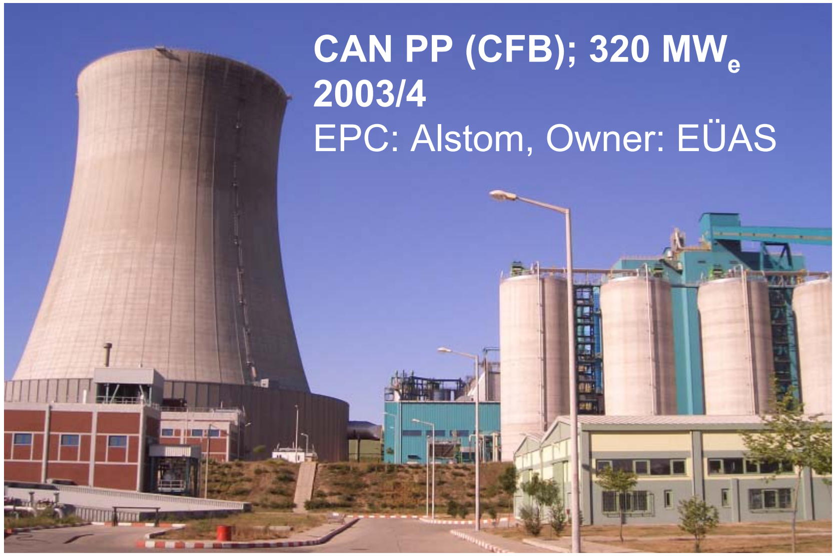
Bilibino NPP 4x12 MW_e (1970s)
Over the Arctic Belt
The only dry cooled nuclear PS in the world

Moscow City 2. Co-gen CCPP
260 MW_e, (2008), winter proof up to -42°C

Strogino Co-gen CCPP, 2x200 MW_e
(2008), winter proof up to -42°C(-43.6°F)

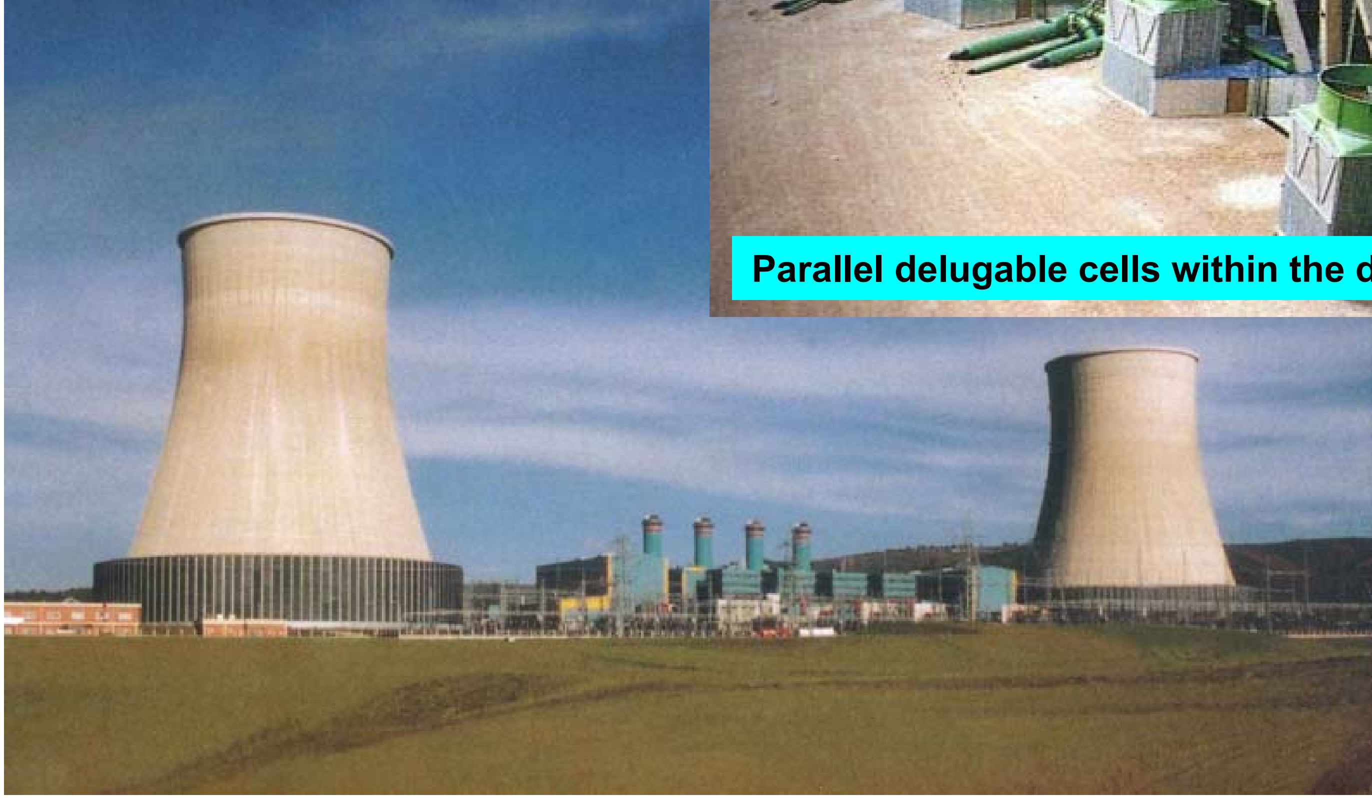
Sochi Co-gen CCPP, 80 MW_e (2004) with supplemental spraying;
exception: mild climate at the sea shore

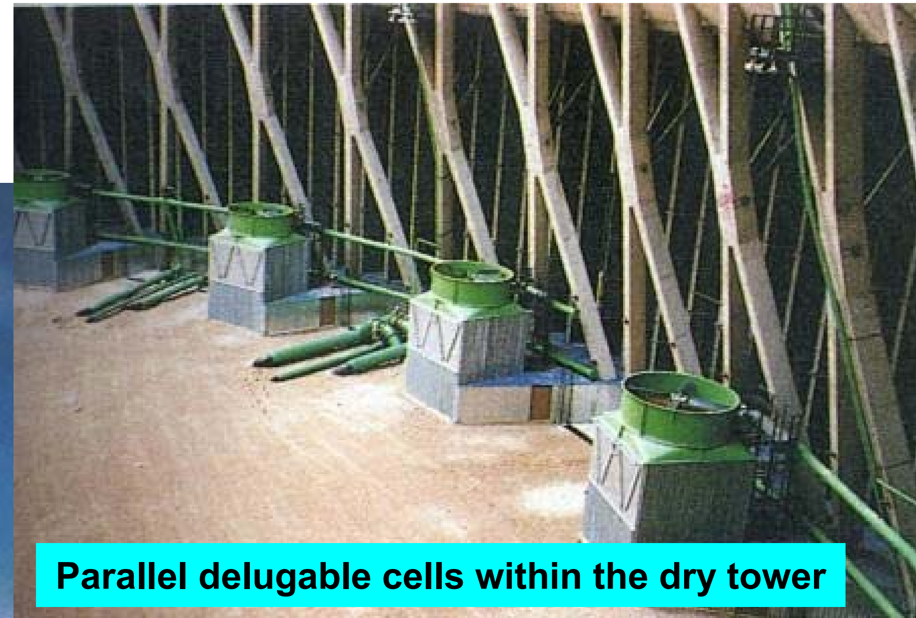
Turkey: superior availabilities



Turkey: closer

1400 MW_e Bursa CCPP (1999)
EPC: MHI / ENKA ; Owner: EÜAS





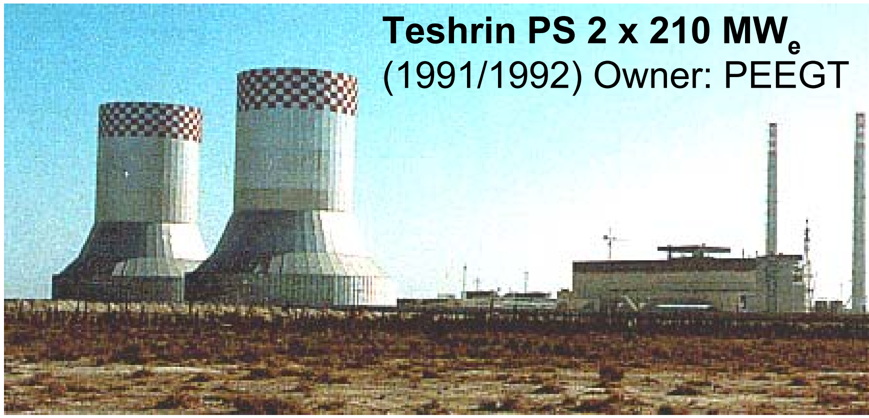
Parallel delugable cells within the dry tower

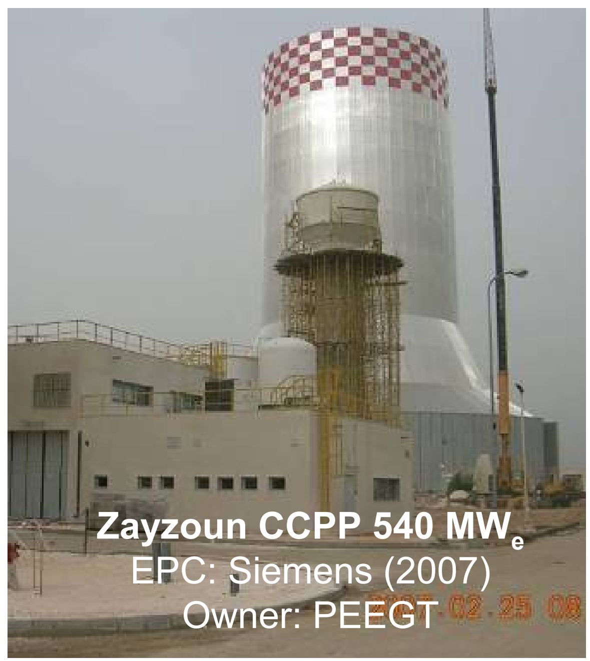
Turkey: closer

3 x 777 MW_e GEBZE & ADAPAZARI CCPP (2002)

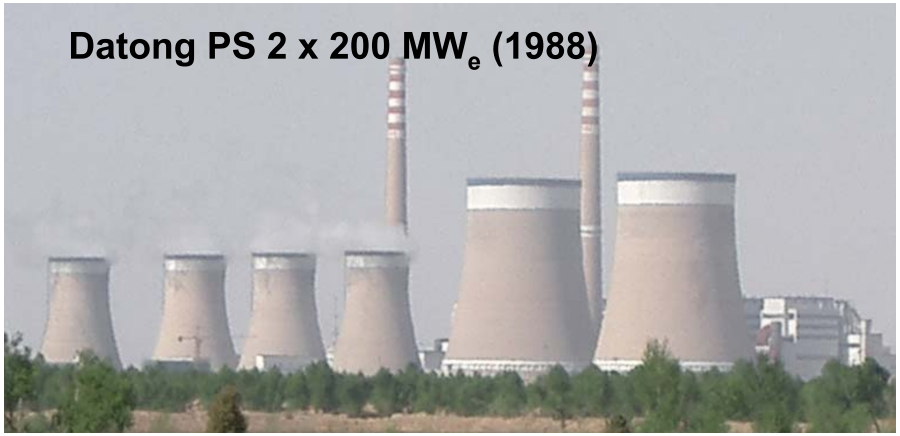
3. … Reference Plants – cont.

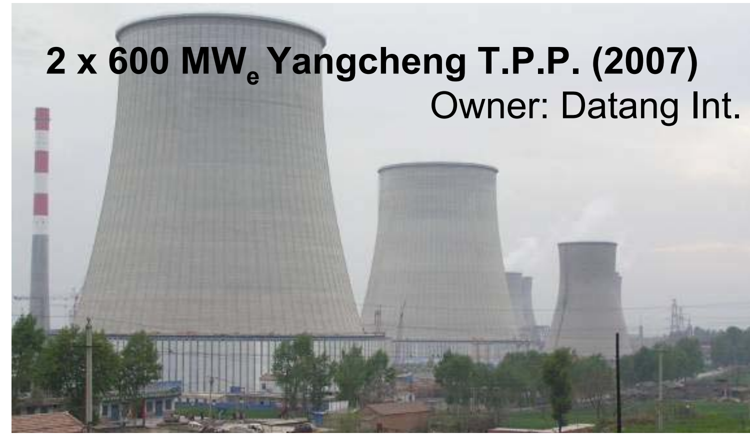
Syria: sizzling deserts





China: cool for coal


Datong PS 2 x 200 MW_e (1988)


2 x 600 MW_e Yangcheng T.P.P. (2007)
Owner: Datang Int.

BaoJi SC PS

2 x 700 MW_e

Owner: Guodian Corp.

Contract: 2007

Comm: 2010

CPC = 25.5 MW_{th} / °K

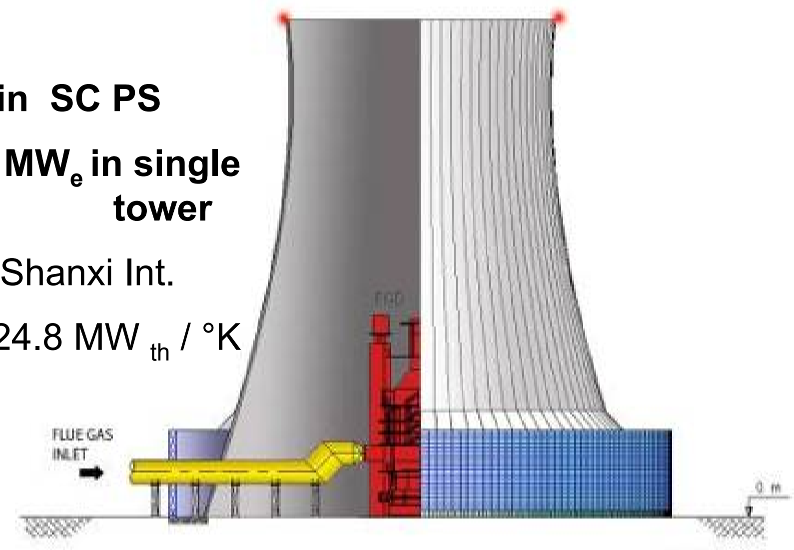
Just under contract negotiation: July 2008

Shan Yin SC PS

2 x 300 MW_e in single tower

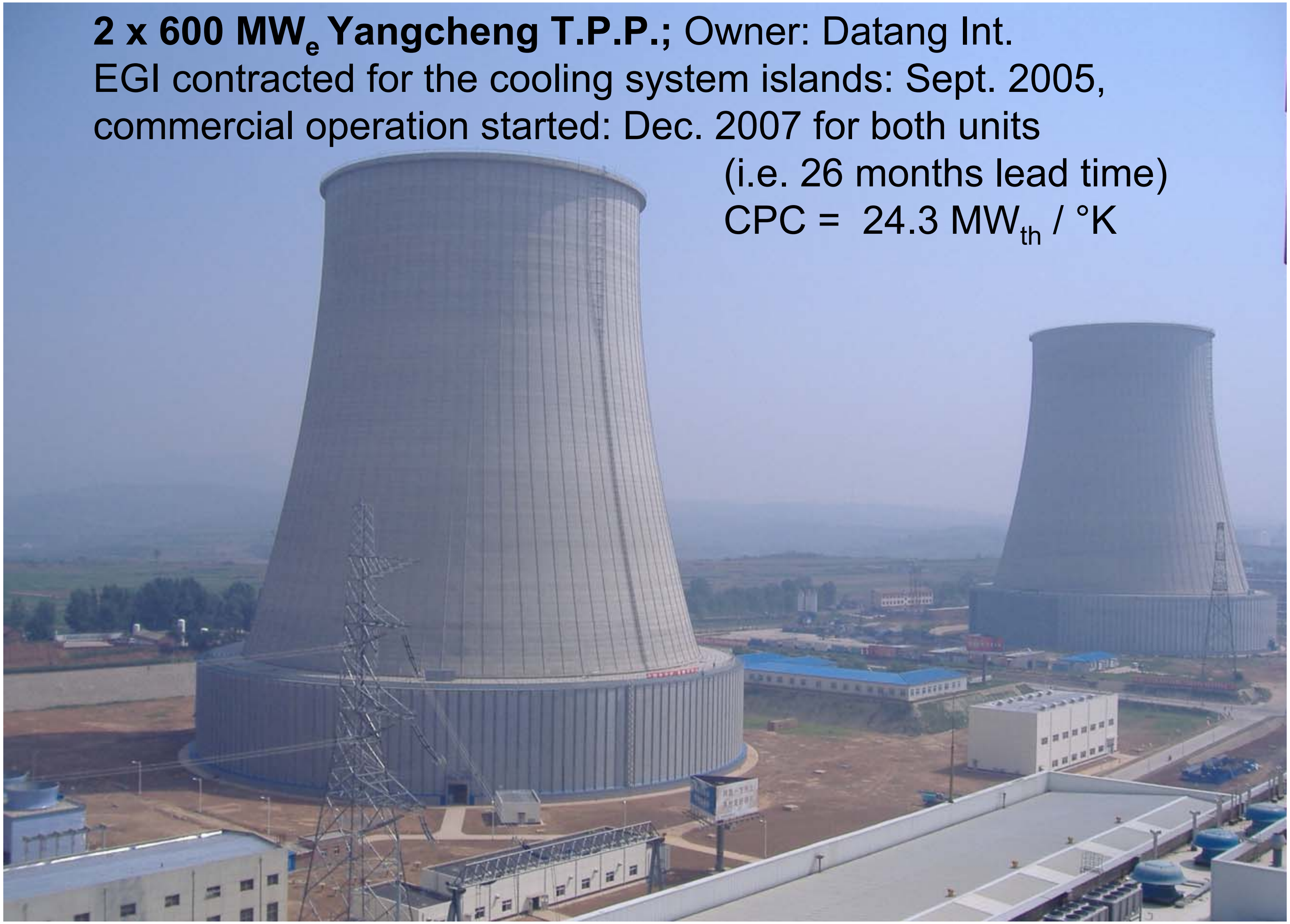
Owner: Shanxi Int.

CPC = 24.8 MW_{th} / °K

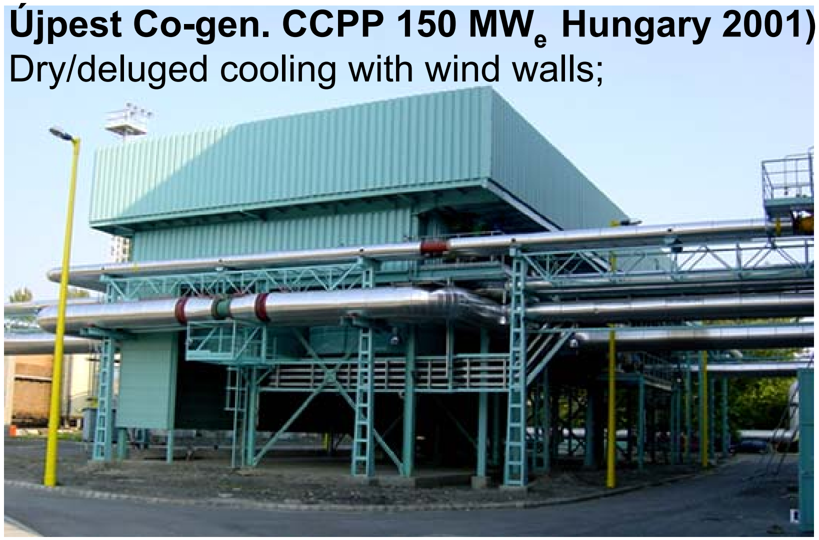


China: closer

2 x 600 MW_e Yangcheng T.P.P.; Owner: Datang Int.
EGI contracted for the cooling system islands: Sept. 2005,
commercial operation started: Dec. 2007 for both units
(i.e. 26 months lead time)
CPC = 24.3 MW_{th} / °K



Mechanical Draft: taming wind



Újpest Co-gen. CCPP 150 MW$_e$ Hungary 2001)
Dry/deluged cooling with wind walls;

Kaneka Co-gen. PS 60 MW$_e$, Japan
Suppl. spraying, induced draft, sea shore

Sochi Co-gen CCPP, 80 MW$_e$ (2004) with
suppl. spraying; induced draft, sea shore

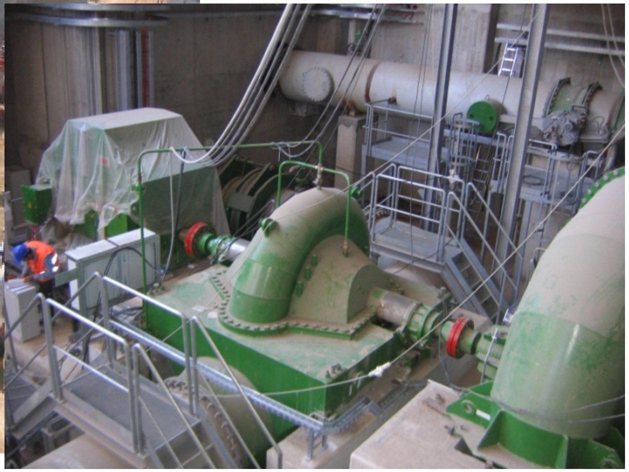
Modugno CCPP 800 MW$_e$, Italy (2008)
Induced draft, low noise, near sea shore

Mechanical Draft: closer

Modugno CCPP 800 MW_e, Italy (2008) near sea shore;
Owner: Energia SpA; EPC: Alstom

- Low noise, induced draft to reduce wind effect and recirculation
- Cooler arrangement adapted to site area constraints

- Hydro-machines



3. … Reference Plants – cont.

Stack-in-tower

Greener & Cheaper flue gas exhausting

FGD-in-tower

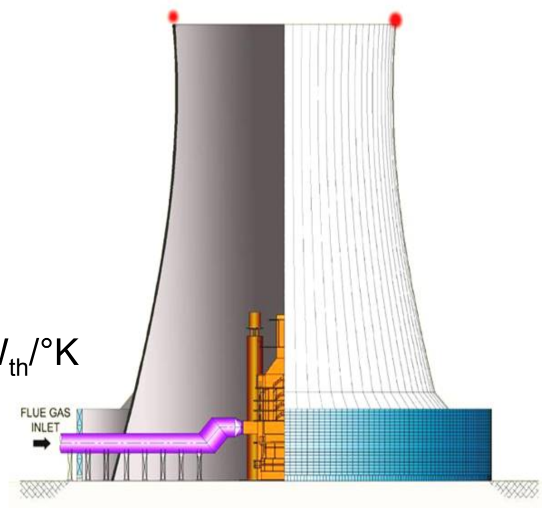
BaoJi SC PS

2×700 MW_e

Contract: 2007

Com: 2010

CPC = 25.5 MW_{th}/°K



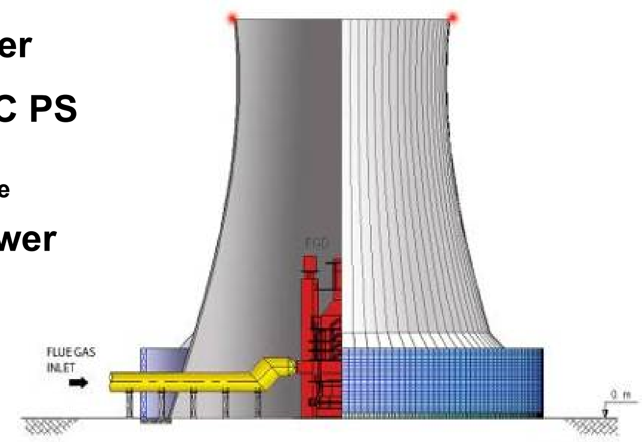
Just under contract negotiation: July 2008

FGD-in-tower

Shan Yin SC PS

2 x 300 MW_e

in single tower



Greener & Cheaper Mátra closer

Mátra PS 800 MW_e - originally commissioned: 1969-1972

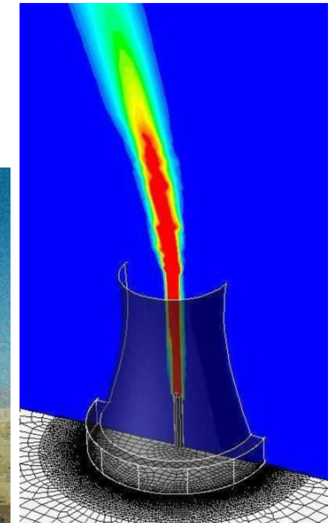
Retrofitted in 1999-2000 incl. 2 FGD plants each put inside one HELLER tower of a 230 MW_e unit, however treating flue gas from 440 MW_e capacity.

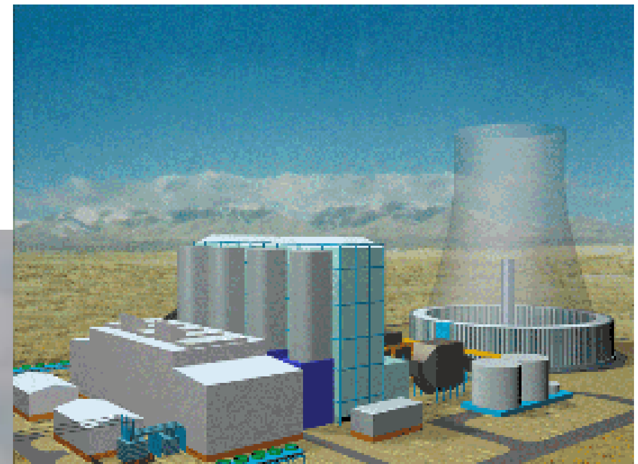
Greener & Cheaper Can closer

320 MW_e CFB based lignite firing Can PP (2003/2004)

Owner: EÜAS; EPC: Alstom

- The dry cooling tower is equipped with parallel delugable coolers





- A single tower shell serves two 160 MW_e power units
- Flue gases are exhausted via the tower: stack-in-tower

Greener & Cheaper Can closer

How flue gases are routed from the boiler to the stack-in-tower at the 320 MW$_e$ Can TPP

Greener & Cheaper BaoJi closer

BaoJi Supercritical PS 2 × 700 MW_e

Owner: Guodian Corp.

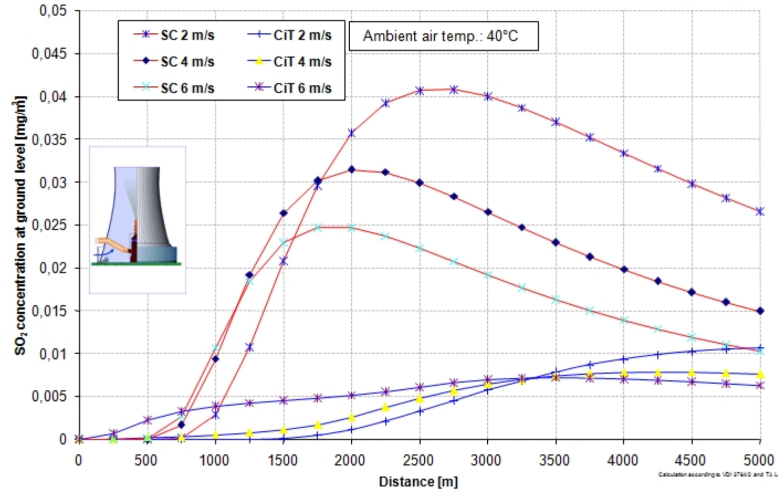
Contract date: Oct. 2007

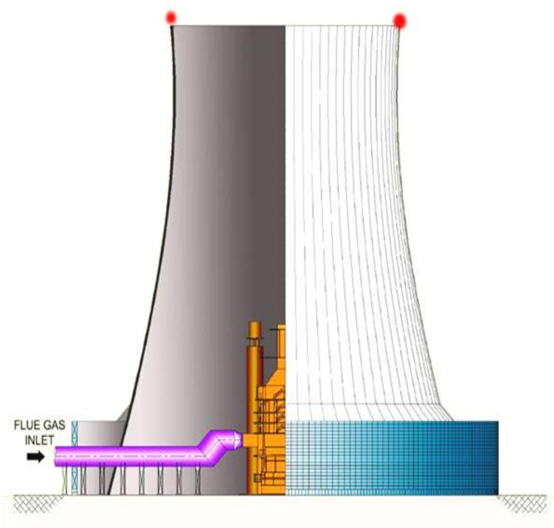
To be commissioned: 2010

CPC = 25.5 MW_{th}/°K

- FGD-in-tower to reduce ground level concentration of pollutants
- OT water treatment (similar to EPRI GL)

LOWER SO_2 CONCENTRATON BY FGD-IN-TOWER (CiT) THAN WITH A 250 M STANDALONE CHIMNEY (SC)

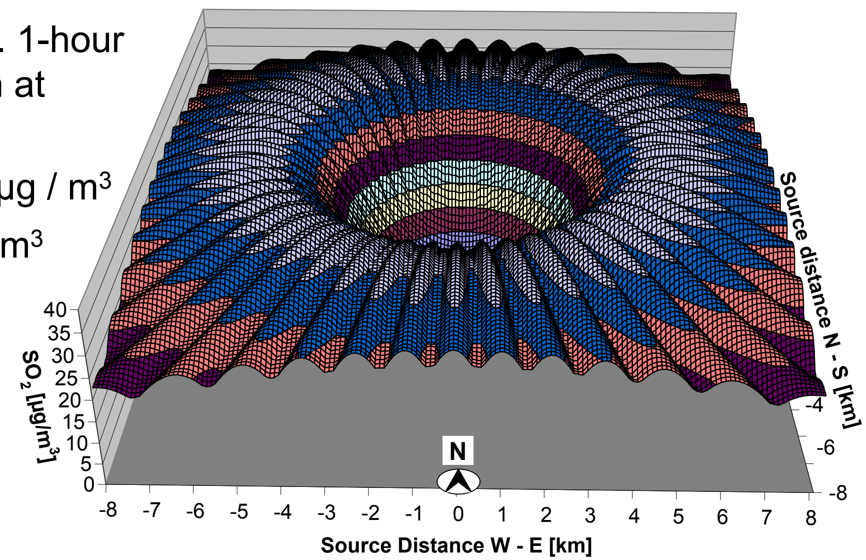




Modeling the max. 1-hour SO_2 concentration at a16×16 km area

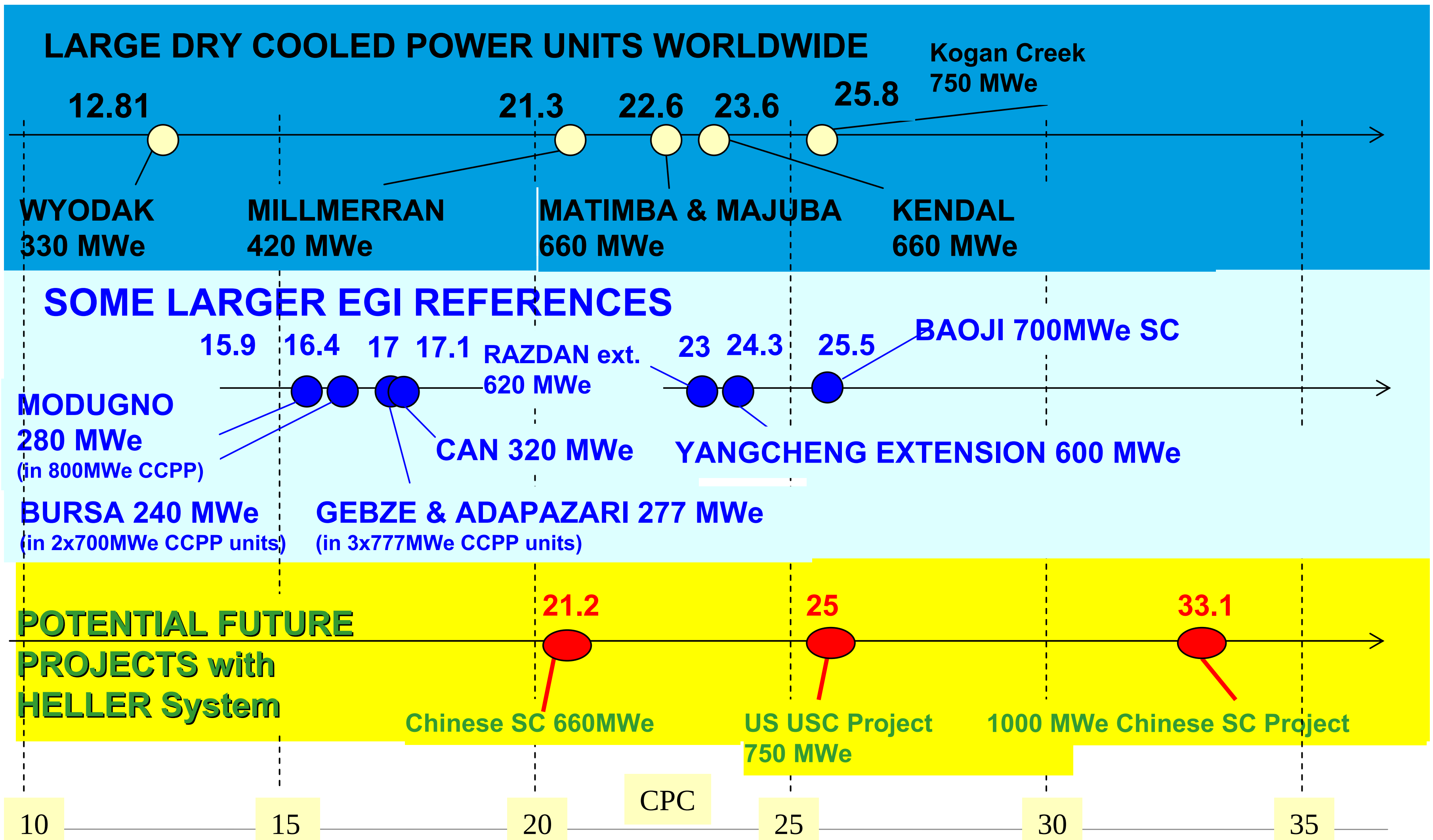
Average max. 29 μg / m^3

Max.max. 38 μg / m^3



Comparison of Dry Cooled Projects by Cooling Plant Capacities

$$\text{COOLING PLANT CAPACITY:} \quad CPC = \frac{Q_{rejected}}{ITD_{overal}} \quad [MW_{th}/\,^{o}K]$$



4. Conclusions to recognize

❖ Features of HELLER System make it well adaptable and complementary to power cycles:

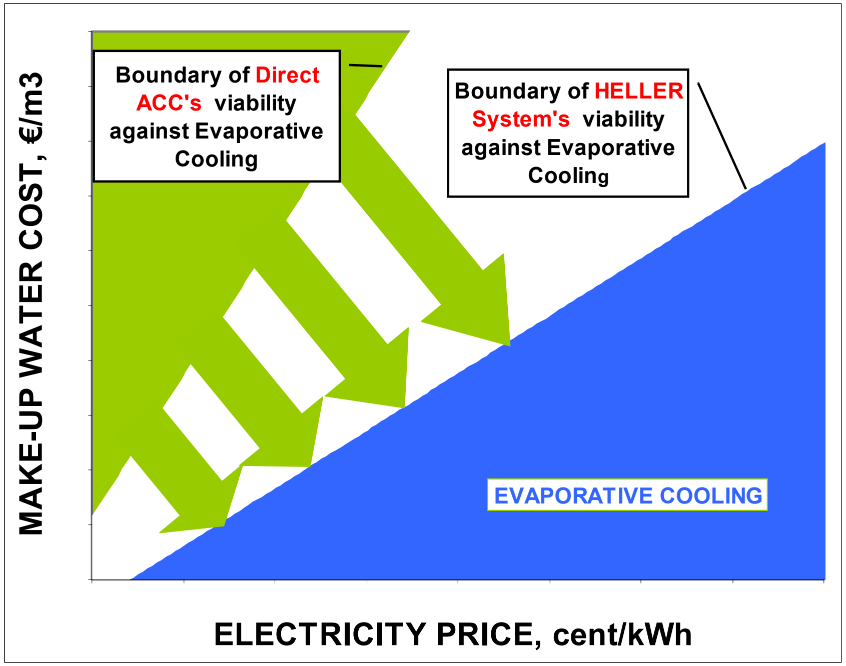
- Highest efficiency among dry cooling options ; the annual average efficiency gap between wet and direct ACC cooled units is shrinked to 2/3 – 1/2 by HELLER System
- Supporting power cycle operational flexibility
- Easing power cycle water chemistry
- Backing improvement in power cycle reliability & availability and reduced maintenance
- Offering greener & cheaper opportunity for flue gas exhausting
- Opportunity to incorporate cost efficient and environmentally compatible wet assistance of a varying extent (dry/wet HELLER Systems)

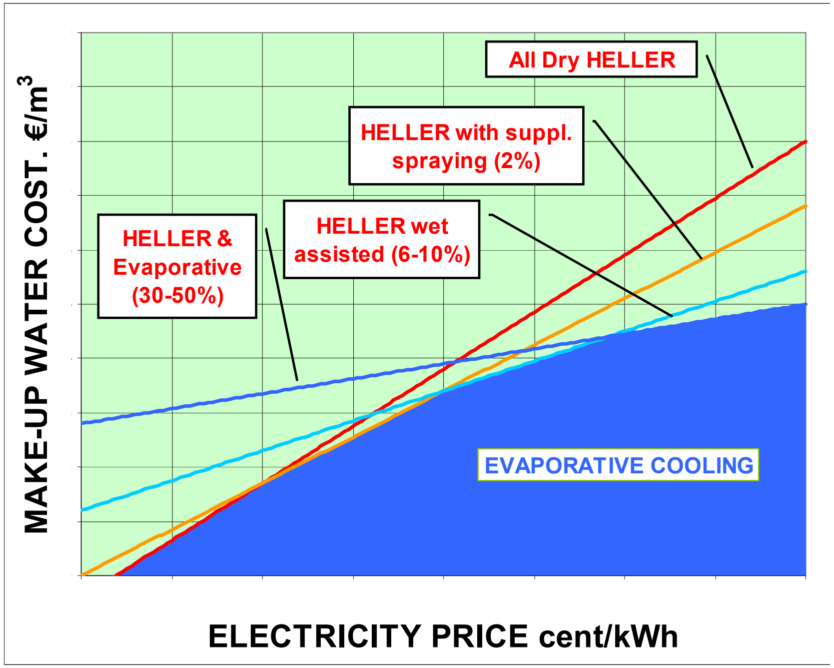
❖ Striving on its positive features , the advanced HELLER System extends the economic viability of water conserving cooling :

- The natural draft HELLER System can be competetive on present value basis against wet cooling even at a medium cooling water make-up cost
- It offers a massive present value cost reduction over direct ACC at comparable capital cost

All these make HELLER System an option what is worthwhile to consider for serving either CCPP, IGCC, coal fired or nuclear power plants.

❖ Comparative economic viability of HELLER Systems





Economic viability of dry cooling vs. wet cooling is extended by all dry HELLER System

HELLER System & its dry/wet derivatives help to conquer further areas of economic viability from wet cooling

References

[1] Balogh, A., Szabó, Z., The Advanced HELLER System – Technical Features & Characteristics, EPRI Conference on Advanced Cooling Strategies/Technologies, June 2005, Sacramento (CA)

[2] Balogh, A., Szabó, Z., Advanced Heller System to Improve Economics of Power Generation, EPRI Conference on Advanced Cooling Strategies/Technologies, June 2005, Sacramento (CA)

[3] Maulbetsch, J.S., Zammit, K.D., Cost/Performance Comparisons of Alternative Cooling Systems, EPRI Conference on Advanced Cooling Strategies/Technologies, June 2005, Sacramento (CA)

[4] Balogh, A., Budik, J., Natural draught tower is vital to indirect dry cooling system, International Power Engineer, May 2006

[5] Balogh, A., Budik, J., Ambient air acts as heat sink in indirect dry cooling system, International Power Engineer, May 2005

[6] Takács, Z., Flue Gas Introduction - Advantages of Dry Cooling Towers, 5th Int. Symp. on Natural Draft Cooling Towers, May 2004, Istanbul

[7] Szabó, Z., Cool for Coal, Journal of Power & Energy 1st quarter, 2004 - Asia Pacific Development

[8] Szabó, Z., Improving the Economics of Water Conserving Power Plant Cooling, Journal of Power & Energy 4th quarter, 2001 - Asia Pacific Development

[9] Balogh, A., Takács, Z., Developing Indirect Dry Cooling Systems for Modern Power Plants, GEA EGI Website, 1998

[10] Szabó, Z., Tasnádi, C., Combined Dry/Wet Cooling Systems for Water Conservation, Cooling Tower Symposium of IAHR, October 1992, Karlsruhe, Germany