China's National Demonstration Coal Power Project Achieves Around 50% Net Efficiency with a 600℃ Class Material

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Preparation and Construction Office of Pingshan Phase II Project

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More efforts are needed in global CO_2 emission reduction to reach climate change goals

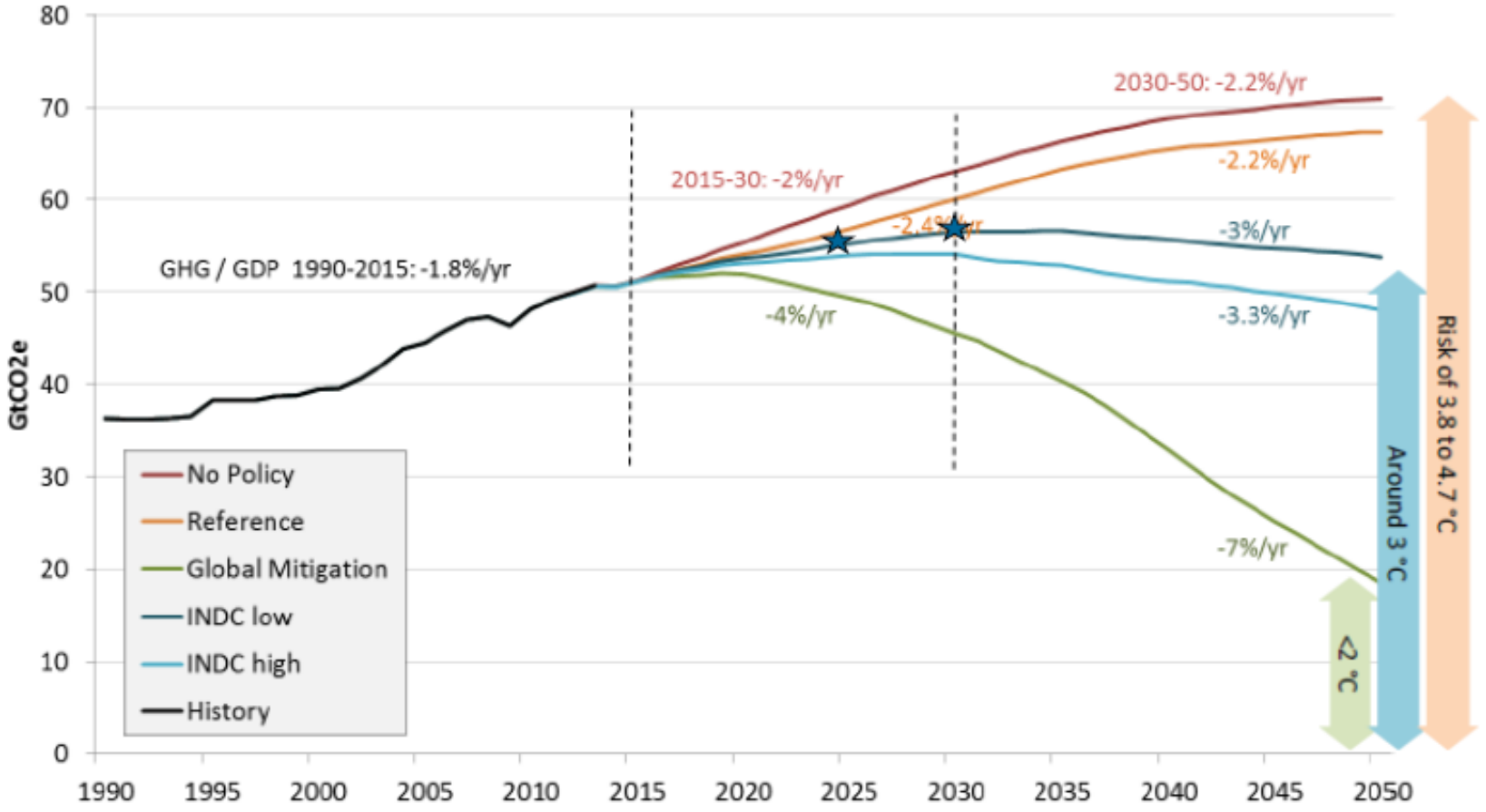


Figure 1: World emissions ($GtCO_2e$, total excluding sinks) and percent change in emission intensity per unit of GDP

Chart source:EC-JRC (2015)

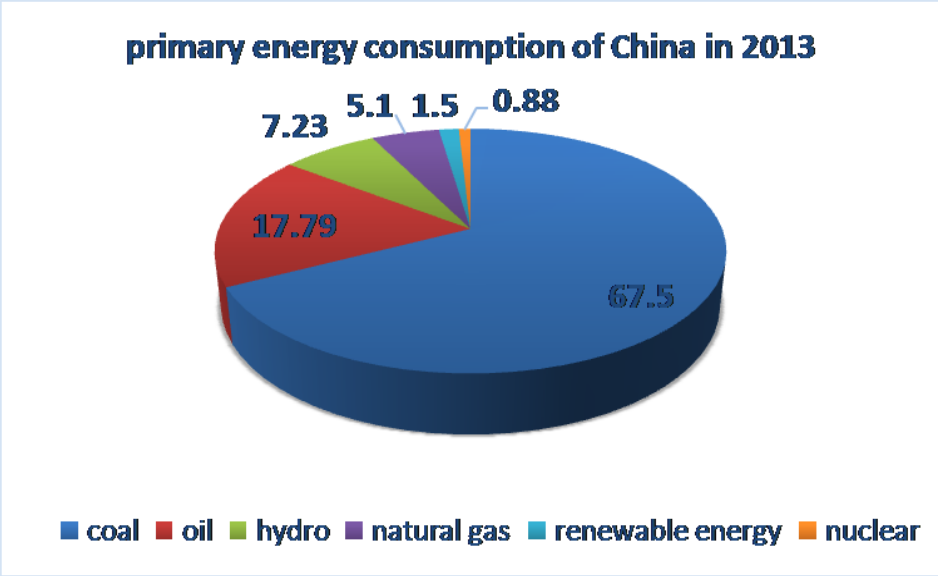
CO_2 emission challenges for coal fired power

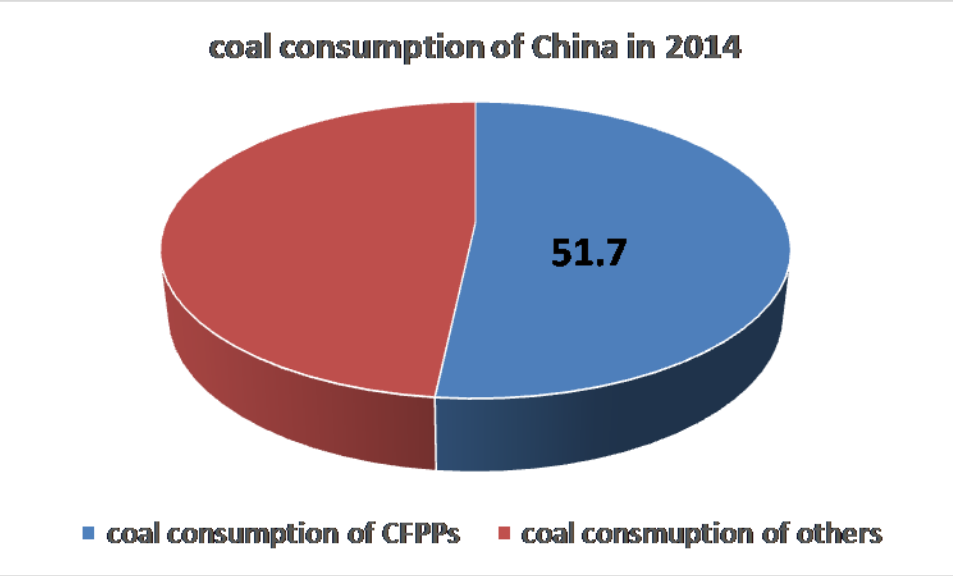
- **The U.S. Environmental Protection Agency (EPA) released its "new source performance standard" (NSPS) on August 3, 2015, requiring new coal power plants in the United States to emit no more than 636g/kWh CO2 based on annual gross unit efficiency.**

- **After detailed researches, EPRI proposed a report according to this standard, " Even with steam temperatures exceeding 800℃ (1500F)—some 200℃ higher than those currently achievable – USC coal plants based on the conventional Rankine steam- electric cycle alone are not capable of meeting the standard"**

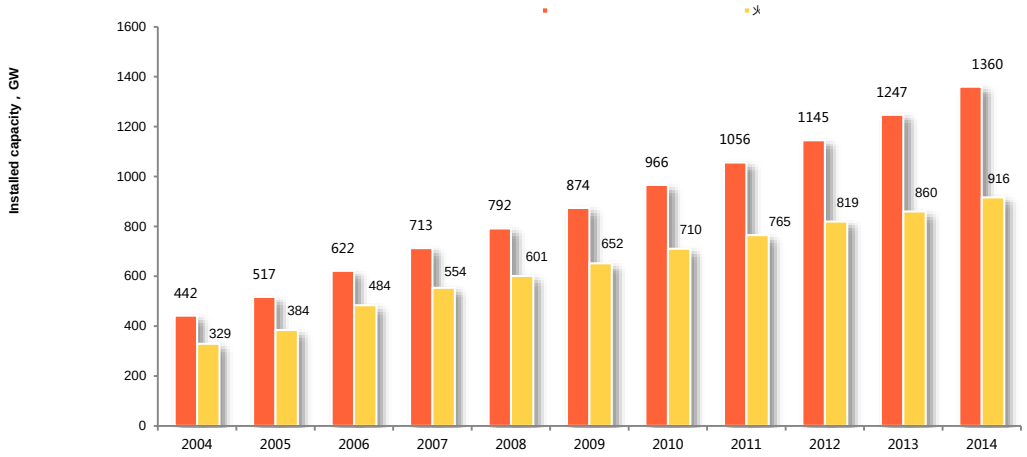
Status of China's energy structure and coal power

- Coal is dominant energy in China, accounting for 70% of primary energy. China is the largest coal producer , coal consumer and therefore the largest CO_2 emitter in the world.
- Coal fired power plants are the largest coal consumer in China, using more than 50% coal.
- Coal power accounts for over 60% of China's total installed capacity and over 80% of China's electricity generation.

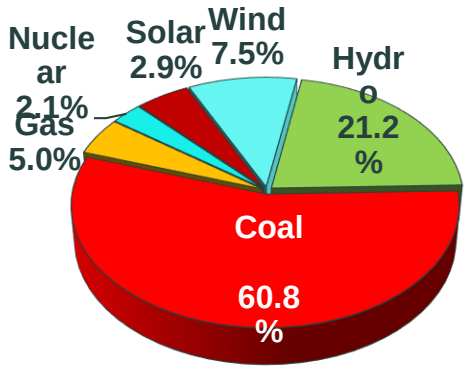




China’s electric power capacity - status and prediction



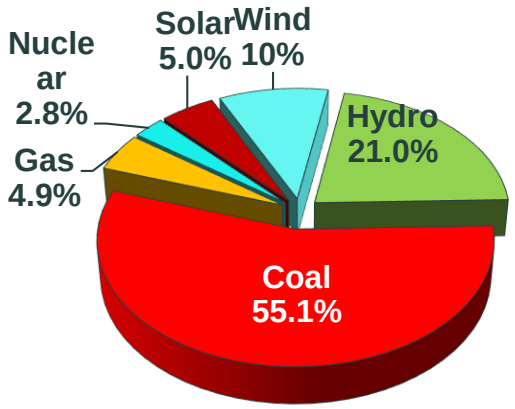
Rapid growth of China’s power capacity in 10 years



Structure of China’s electric power in 2015

Year	Unit	Total capacity	Coal	Gas& others	Hydro	Wind	Solar	Nuclear
2015	GWe	1,510	944.7	78.01	328.46	116.49	45.38	32.40
	%	100	60.8	5.0	21.2	7.5	2.9	2.1
2020	GWe	2,000	1,100	122	420	200	100	58
	%	100	55.1	4.5	21.0	10.0	5.0	2.9

Status and prediction of China’s electric power in 2015 and 2020

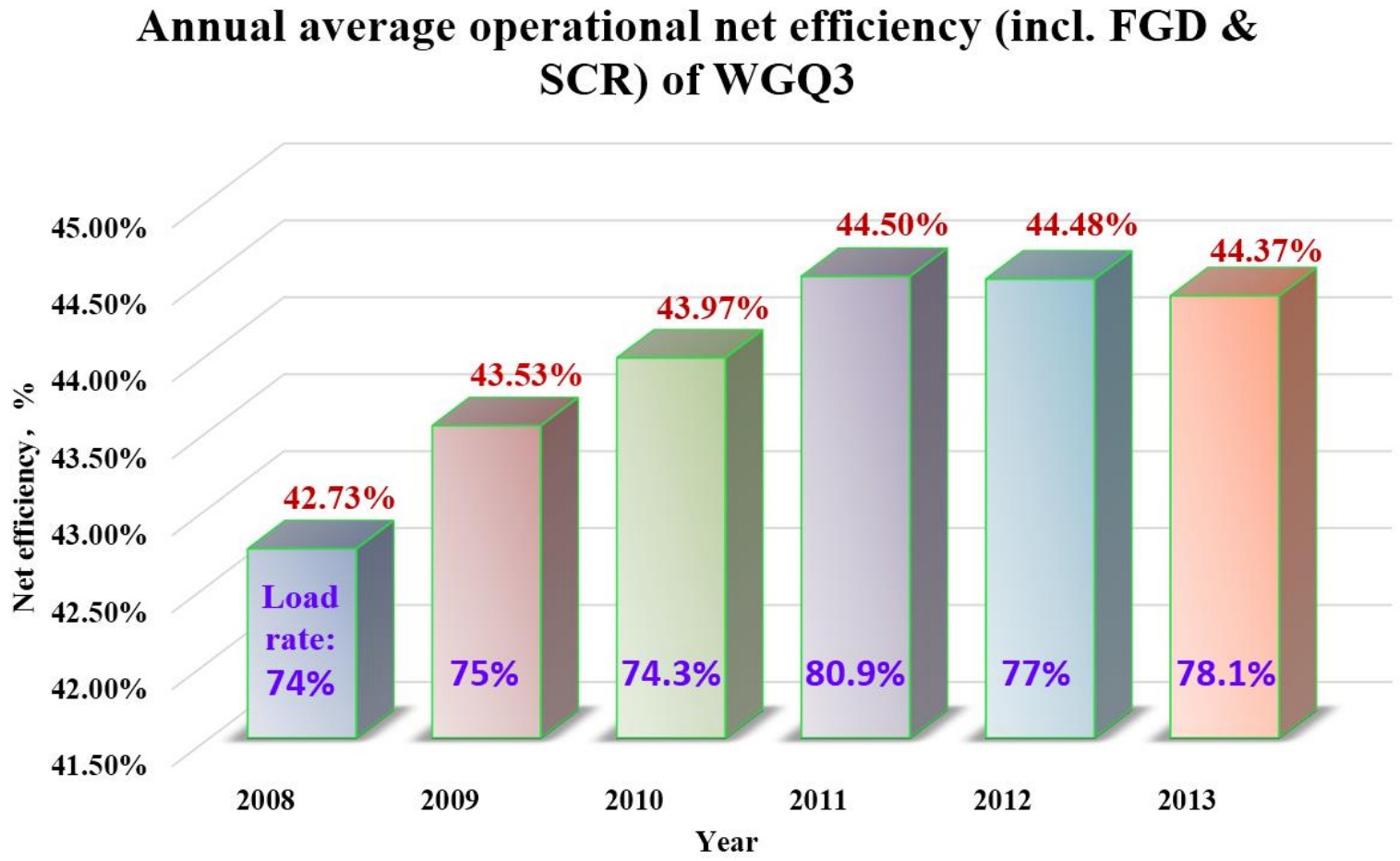


Prediction of China’s structure of electric power in 2020

Construction of Shanghai Waigaoqiao No.3 Power Plant (WGQ3):

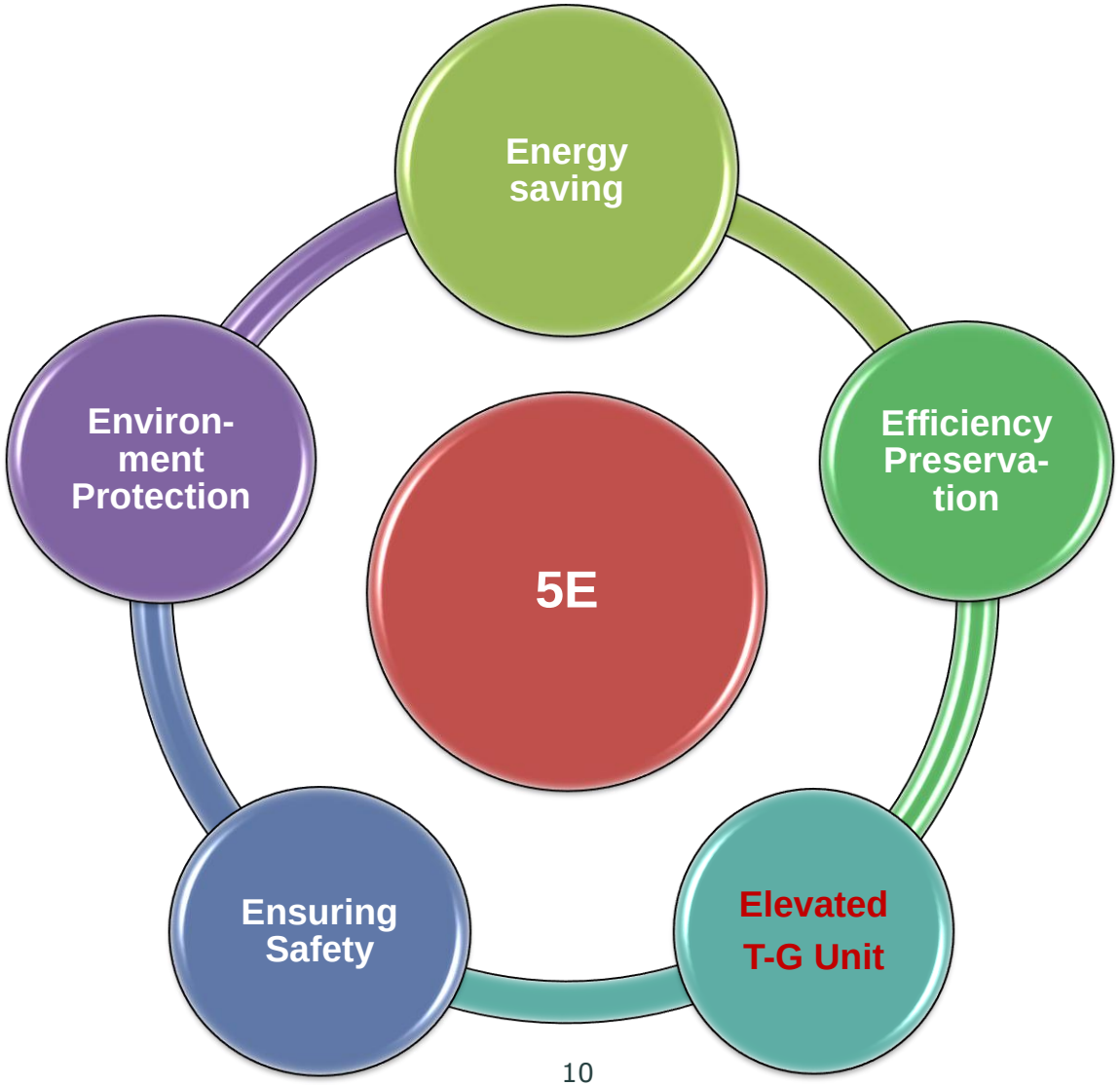
2X1000 MW USC units, started in September, 2005, finished in June, 2008.

- **Annual average net operating efficiency of WGQ3 reaches 44.5% in 2011 under 81% average load**



*Lunen plant in German, awarded as the most efficient CFPP of Europe in 2014, annual net efficiency 44%

Feng's 5E Innovative Technologies for Efficiency, Safety and Emission Control



Development trend of coal power in China

- **China's coal power is serious overcapacity after more than ten years' high speed development of 1000MW/660MW USC units.**
- **China's coal power now is developing from single reheat to double reheat, and researching from 600℃ to 700℃ USC.**
- **Need to be solved: 700℃ materials are immature and very expensive. Double reheat are much more costive and complicated.**

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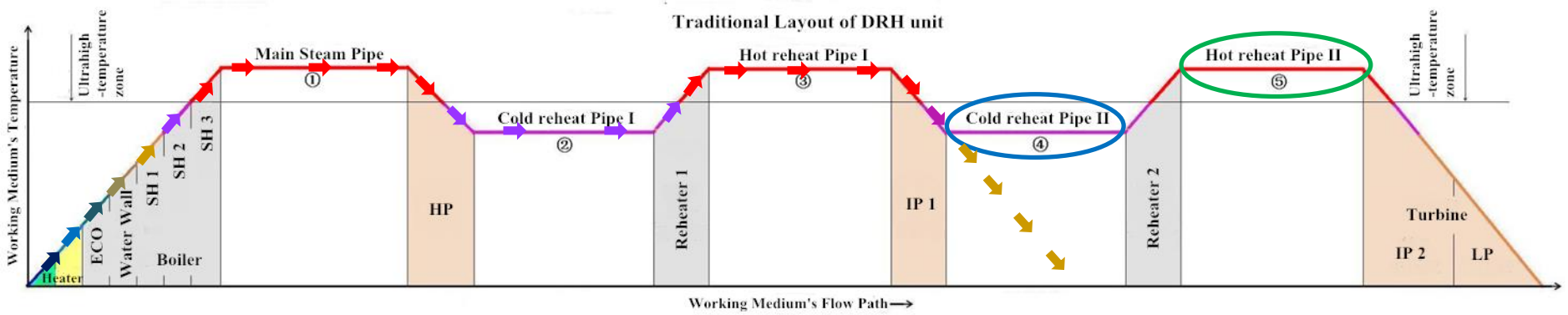
Piping problems of conventional double reheat design

- For conventional double reheat technology, the main steam and reheat steam piping would be routed with a long distance between the boiler and turbine, can be 200m for a single pipe(1000MW unit), specifically the reheat steam piping would go back and forth for twice. And to the large capacity unit, more piping material would be used. This would cause the following problems：

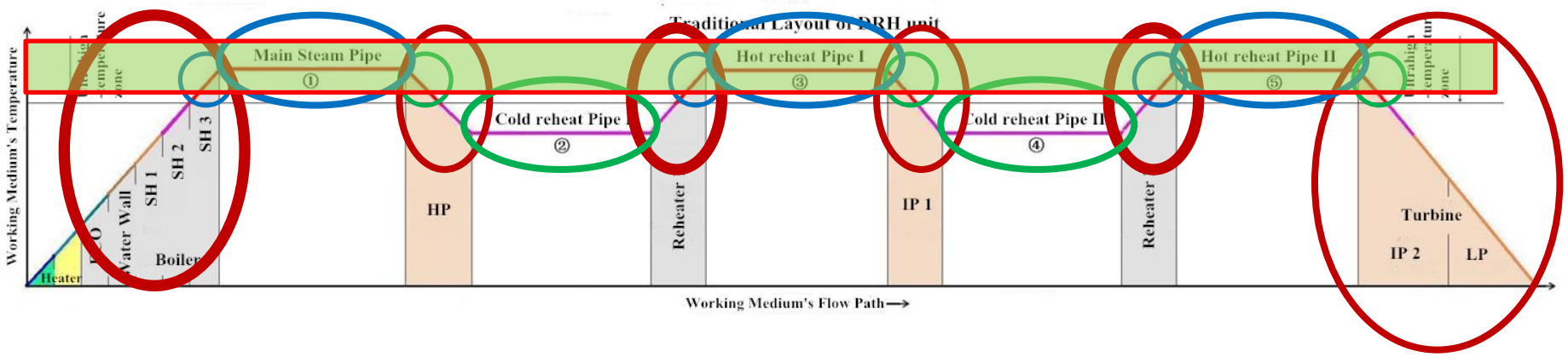
1. the lower pressure reheat piping -- large diameter, difficult arrangement.
2. the cost failed the commercialization.
3. the pressure and heat losses lead to an efficiency reduction.
4. increase the storage steam greatly, thus increase the inertia of load adjustment for turbine-generator remarkably.



Working medium’s flow path of double reheat unit with conventional layout

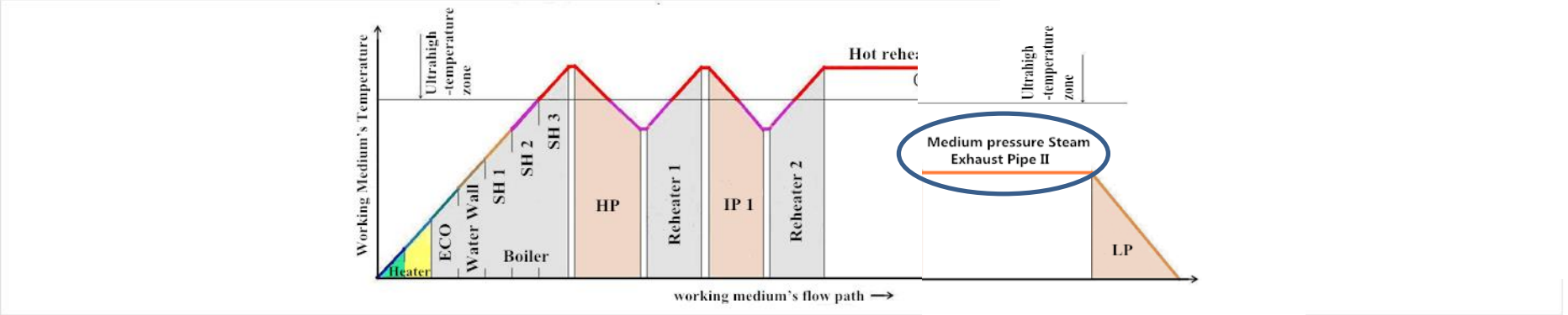
Medium Characteristics in a double reheat unit

- In boiler, the working medium flows from economizer to final superheater, and to reheater I and reheater II, the medium temperature is increasing.
- In turbine, the medium works in the HP, IP I, IP II and LP, its temperature is decreasing .
- The steam temperature in the critical piping is almost constant .
- In high temperature section, high temperature resistant material is required. 700 ℃ unit, Ni-based alloy will be used.
- For boiler, the final superheater and final reheater use the high temperature resistant material.
- For turbine, the front stages of the HP and IP turbine choose the high temperature resistant material. Welding technology makes the expensive and conventional material possibly be one part as rotor and cylinder.
- The exceptional part, the critical piping, uses the high temperature resistant material. High cost and high losses takes place .



What will happen if the HP and IP casings are positioned near the boiler's final headers?

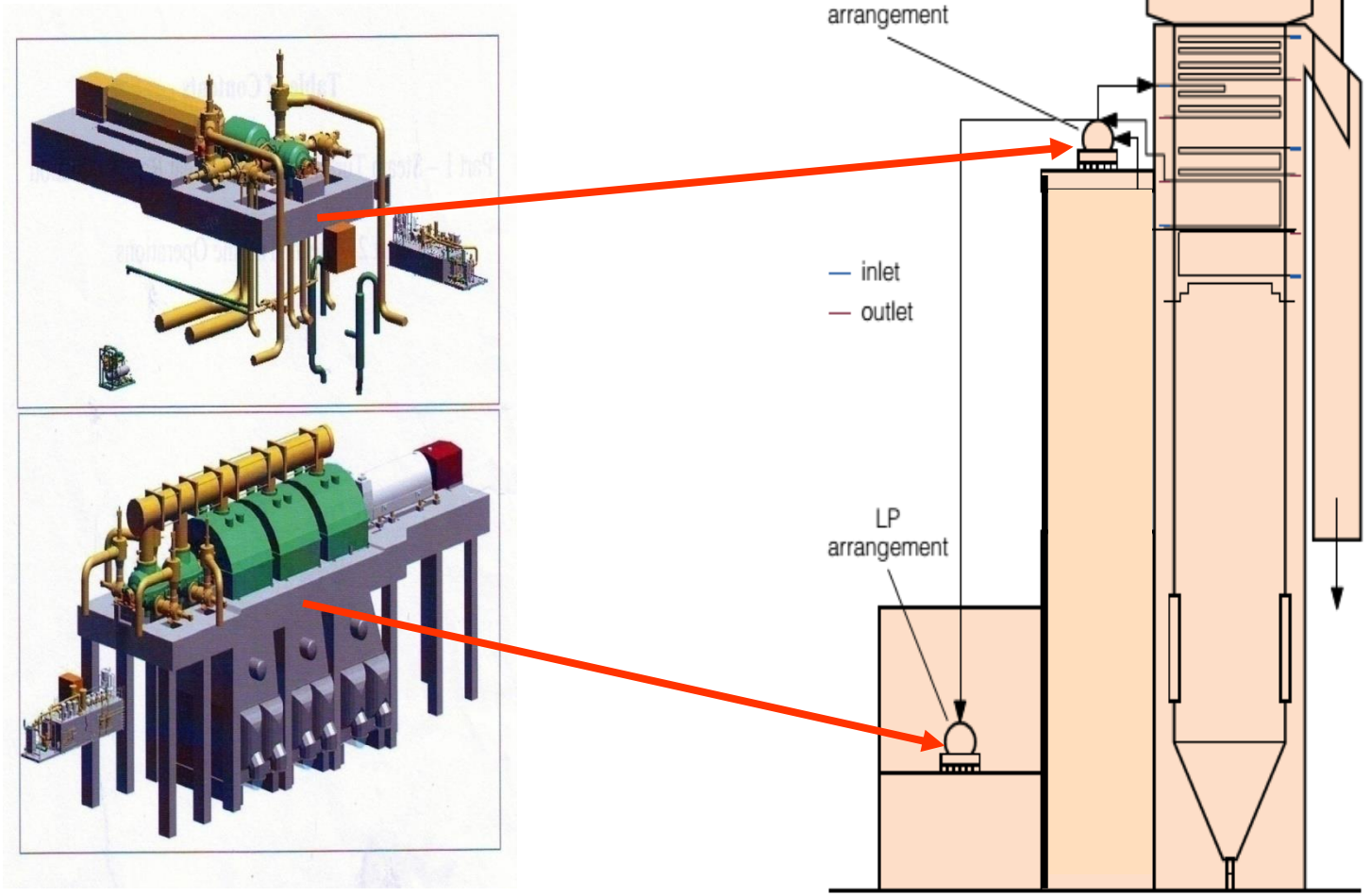
1. To set the HP casing near the superheater outlet headers, the main steam pipe ① and cold reheat steam pipe I ②would be minimized.
2. To set the IP1 casing in the same shaft with HP casing, the hot reheat steam pipe I ③ and the cold reheat steam pipe II ④ would also be shortened.



As is shown in the Fig, the pressure loss and heat loss have been reduced.

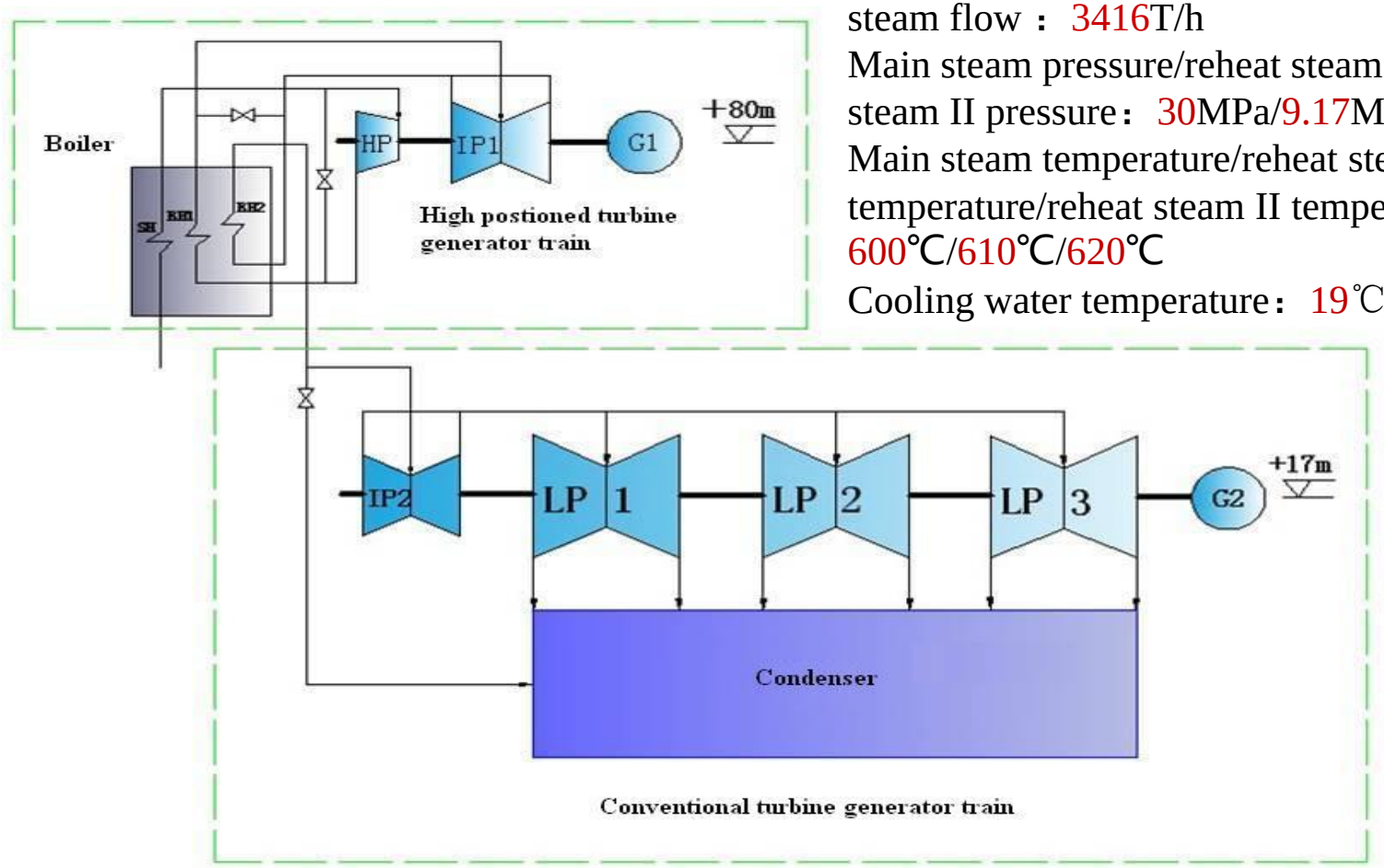
If the remaining high temperature steam pipe ⑤ need to be shortened. The second IP turbine can also be lifted to near the reheater headers. Meanwhile, IP2 turbine exhausting pipe should be prolonged.

✓ Feasible Solution: Elevated plus conventional layout



Patents of this new design have already authorized by China, USA and EU

1350MW Double Reheat USC Elevated and Conventional Layout



Design parameters:

Rated output: 1350MW

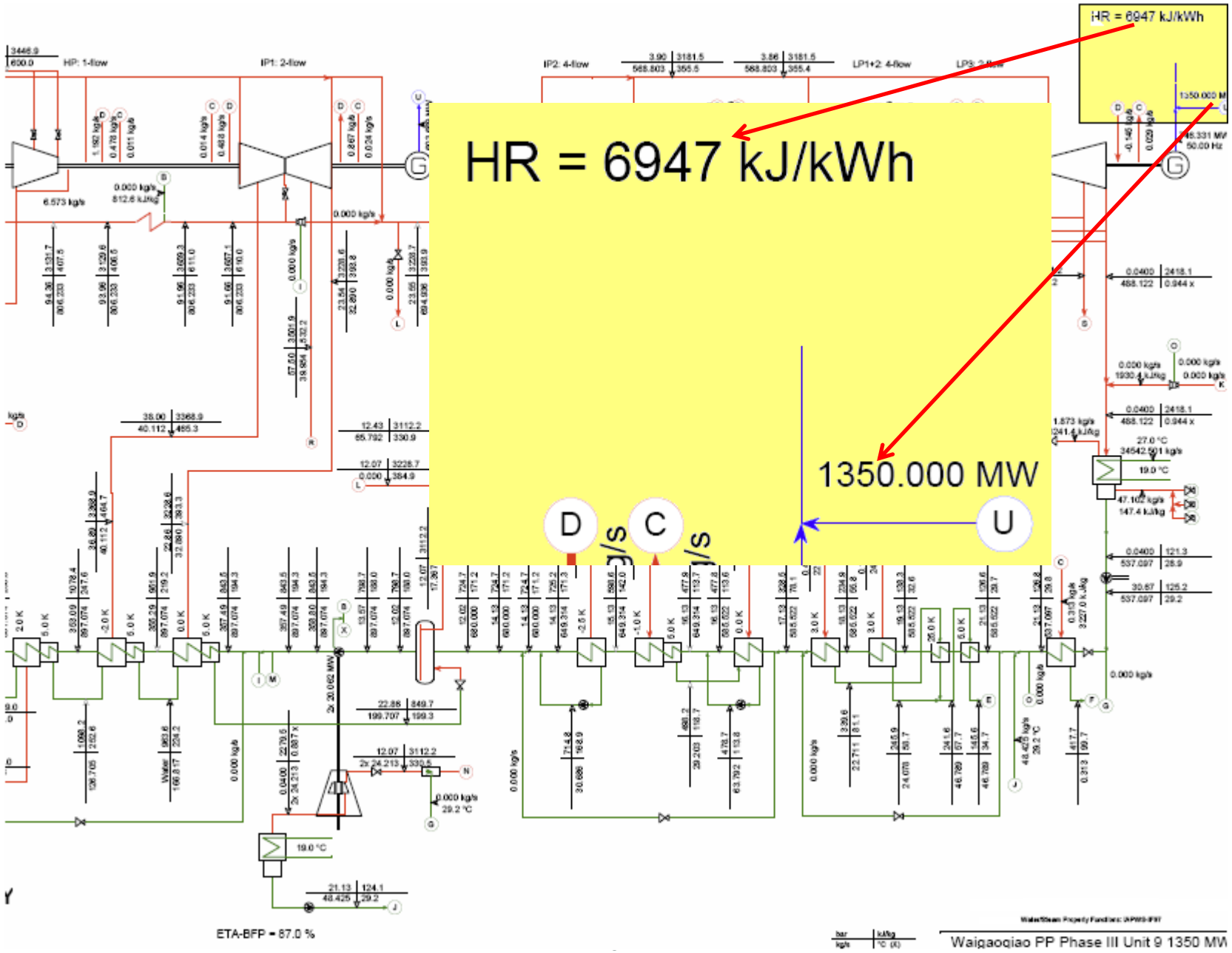
Rated main steam flow: 3229T/h, Max main steam flow : 3416T/h

Main steam pressure/reheat steam I pressure/reheat steam II pressure: 30MPa/9.17MPa/2.25MPa

Main steam temperature/reheat steam I temperature/reheat steam II temperature: 600℃/610℃/620℃

Cooling water temperature: 19℃

First version HBD of 1350MW double reheat USC unit



Benefits of Elevated & Conventional Layout Compared with Conventional Layout

Benefits of Elevated & Conventional Layout Compared with Conventional Layout	Reduction of heat rate
Reduction of pressure drop of steam piping	**42kJ/kWh**
Optimization of second reheat pressure	**33.4kJ/kWh**
Increase of steam quality for last stage of the LP casing	**23.8kJ/kWh**
Optimization of LP exhaust steam losses	**47.9 kJ/kWh**
Total reduction of heat rate due to the elevated / conventional turbine layout	**147.1kJ/kWh**
Elevated / conventional turbine layout can greatly reduce the length of high temperature steam piping compared with that of conventional 1000MW double reheat USC, the cost savings for imported P92 piping will be about 30 million US dollars.	

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The Development of Pingshan Phase II Project

- 2007 -- Elevated and Conventional Layout design proposed by Prof. Feng
- 03/2009 -- Initiation of Engineering Researches
- 2011 -- Technical evaluation organized by CPECC
- 03/2015，Approval of technical evaluation organized by NEA of China
- End of 2015 – Named as national demonstration project by NEA of China
- 12/28/2016 -- Project approval

a. Further optimization of thermal system based on E+C layout

- **Proper improvement of steam temperature and pressure – still use mature 600℃ material**

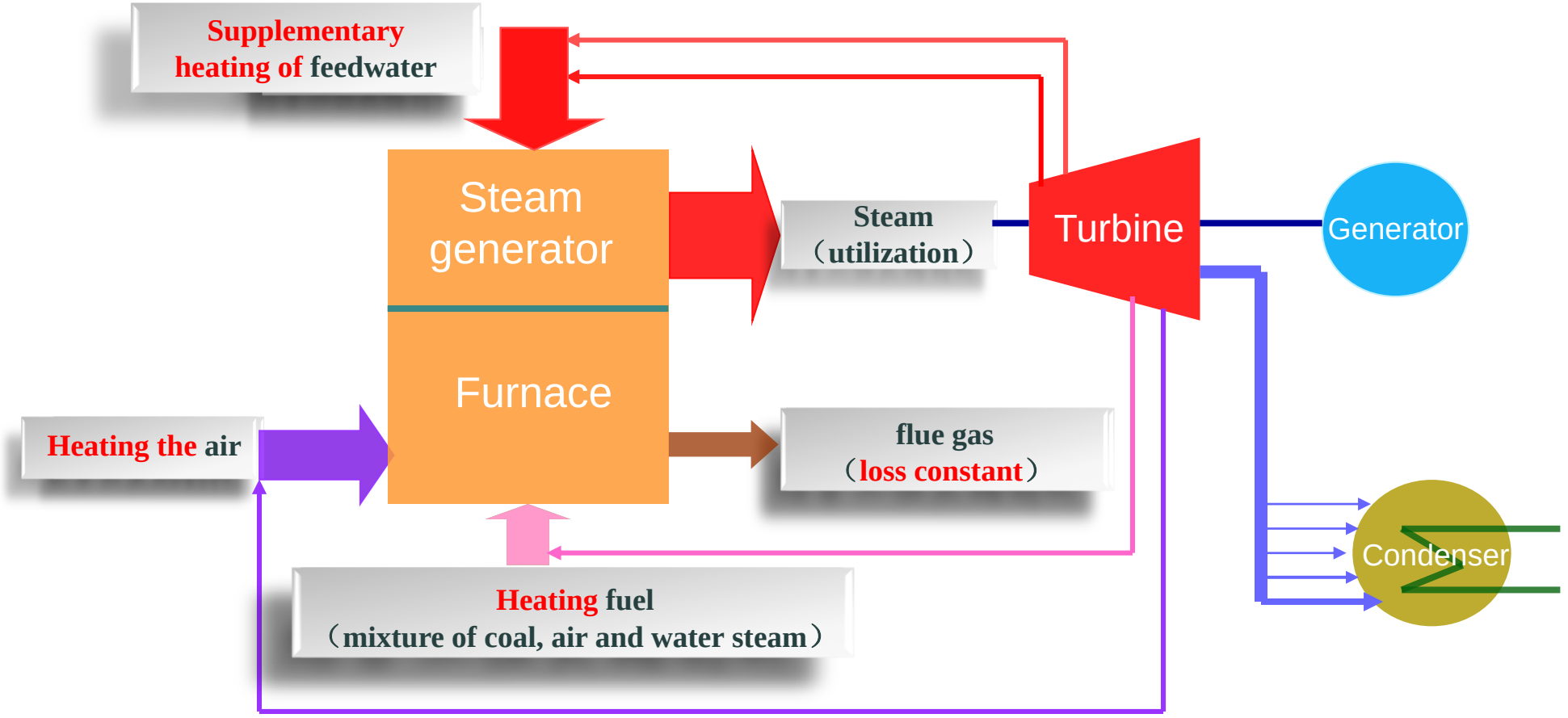
- **Main steam: 30MPa →31.6MPa, 600℃ → ≈ 610℃**
- **Reheat temperature: 610/620℃ → ≈ 630/630℃**

- **3 LP casing make it possible to add a low pressure regeneration extraction, reducing the heat rate by about 10kJ/kWh**

- **The heat rate of turbine, after optimization of thermal system, can reach as low as 6882kJ/kWh**

b. A series of Generalized Regeneration Technologies

Expand the regenerative medium from feedwater to water, air and coal

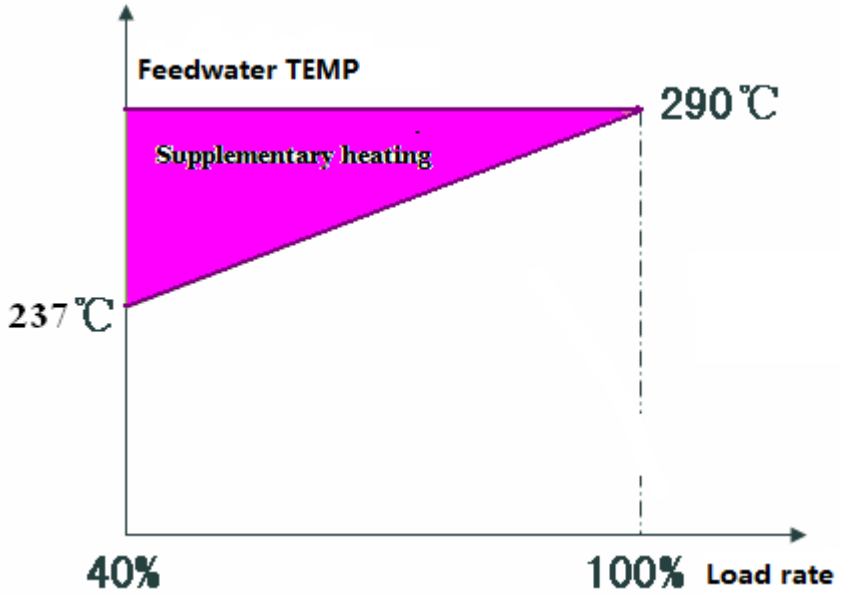


c. Narrow the gap between design and operating UNE (unit net efficiency)

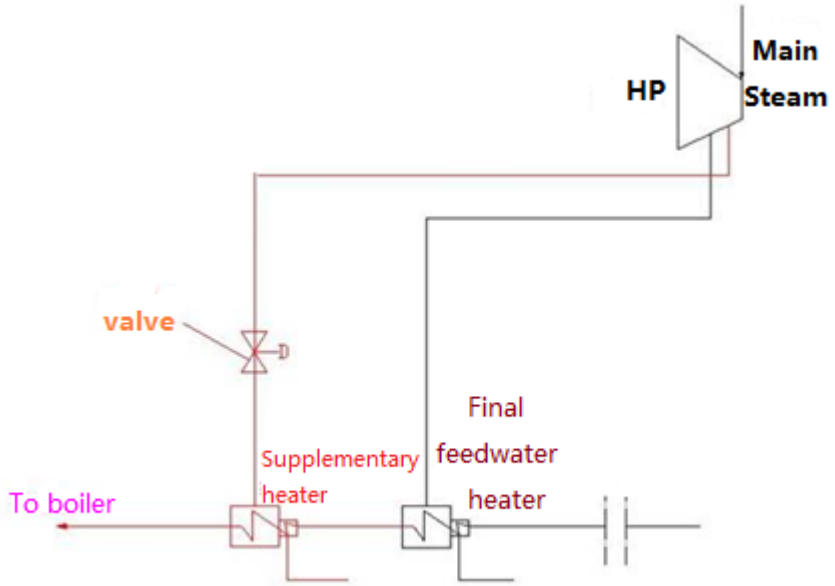
- **Main reasons lead to the gap between design and operating UNE:**
  - **Load Change – Combined frequency regulation technologies with condensate water and extractions**
  - **Low load – Decrease of turbine, boiler and auxiliaries efficiency**
  - **Different seasons – Especially Summer and Winter**
  - **SPE problems – efficiency drop and tube explosion**

Low load – Flexible Regeneration Technologies (Turbine)

- **Solution: add an adjustable extraction steam and a corresponding additional feedwater heater, keeping the feedwater temperature at the rated load level**

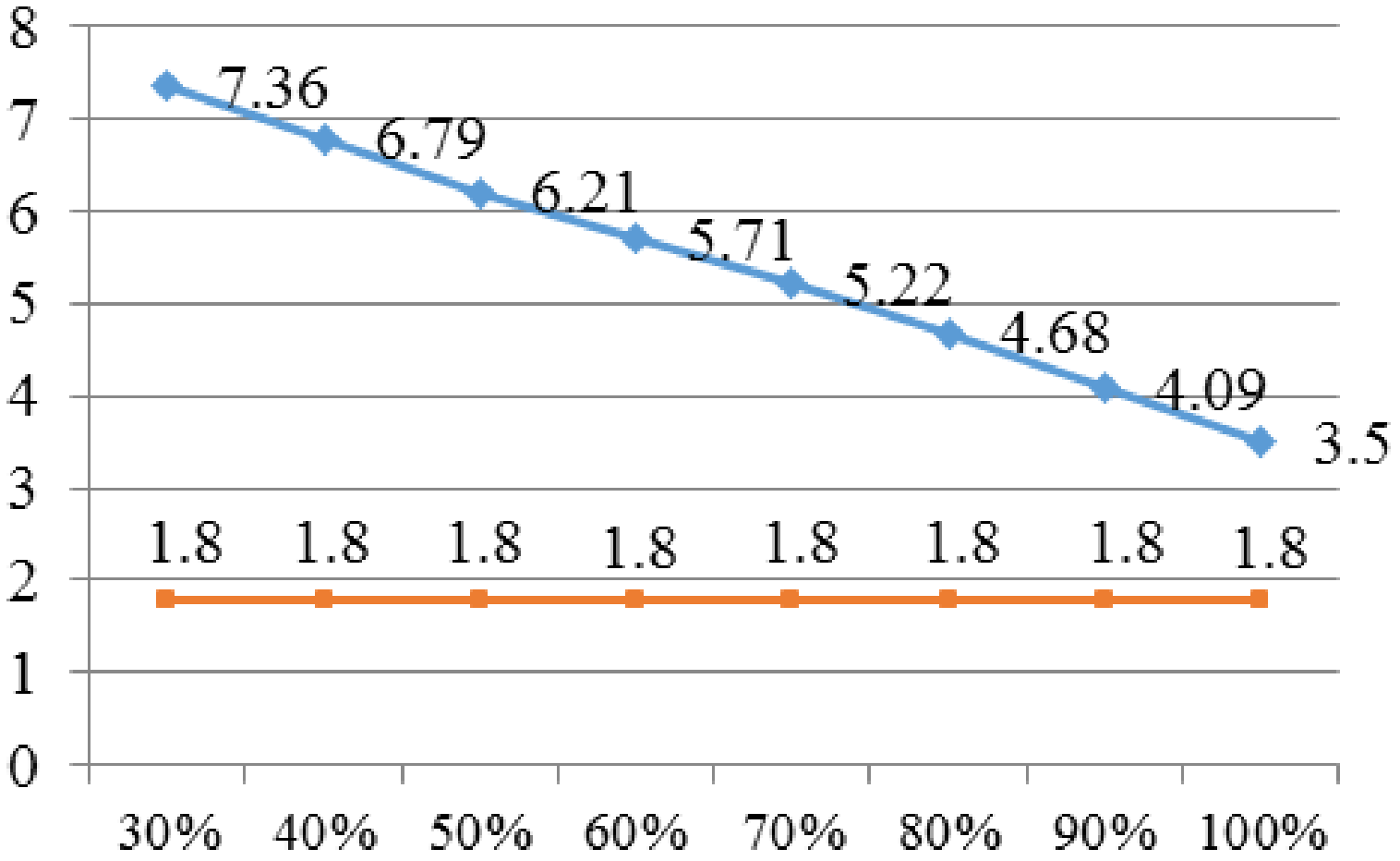


The Schematic Fig. for extraction steam heating feedwater



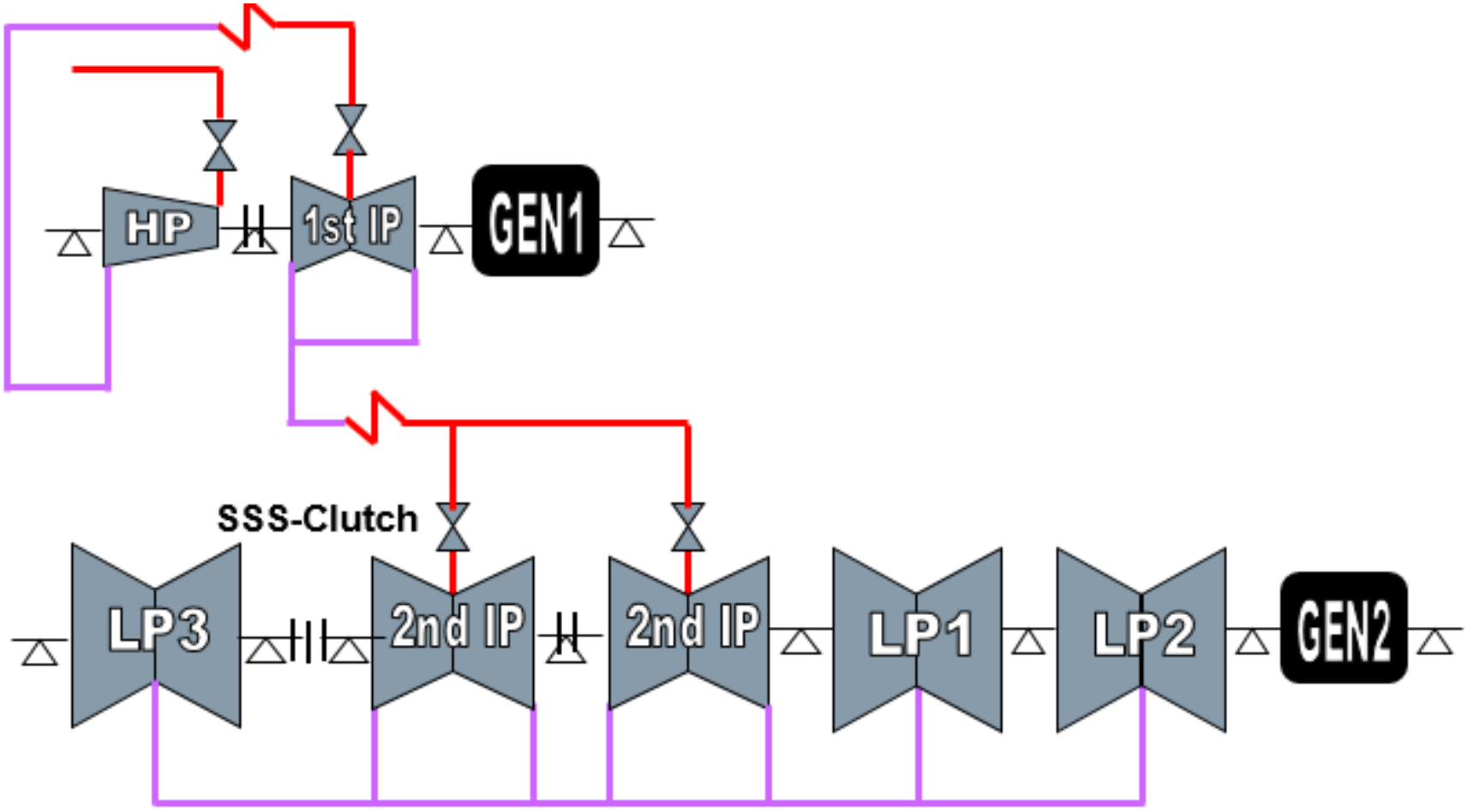
The system Fig. for extraction steam heating feedwater

Low Load – Low O_2 & NOx combustion within whole load range (Boiler)



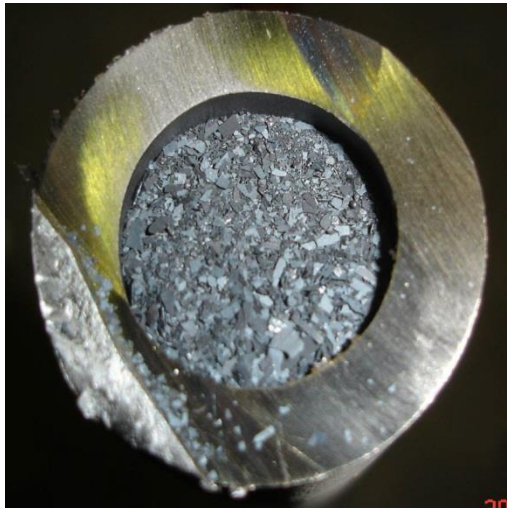
Low Load -- Centralized Frequency Variable Power System (Auxiliaries)

Season Difference – Switching off a LP Casing in Summer



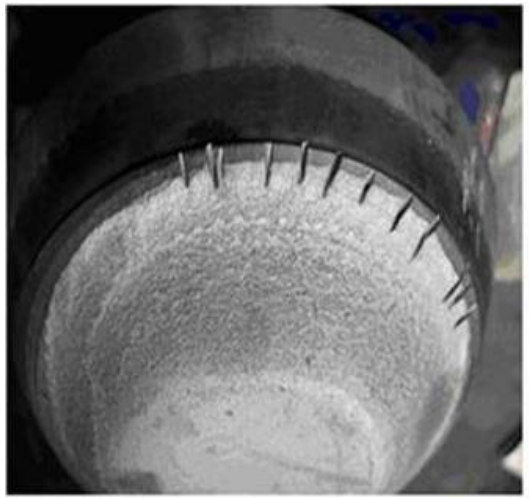
SPE problems --A series of efficiency-preservation technologies

- **SPE problem has troubled the global power generation industry for decades, more serious for SC/USC units**
- **SPE problem not solved, remarkable efficiency improvement will be consumed.**



Tube Blocked by Oxide Scales

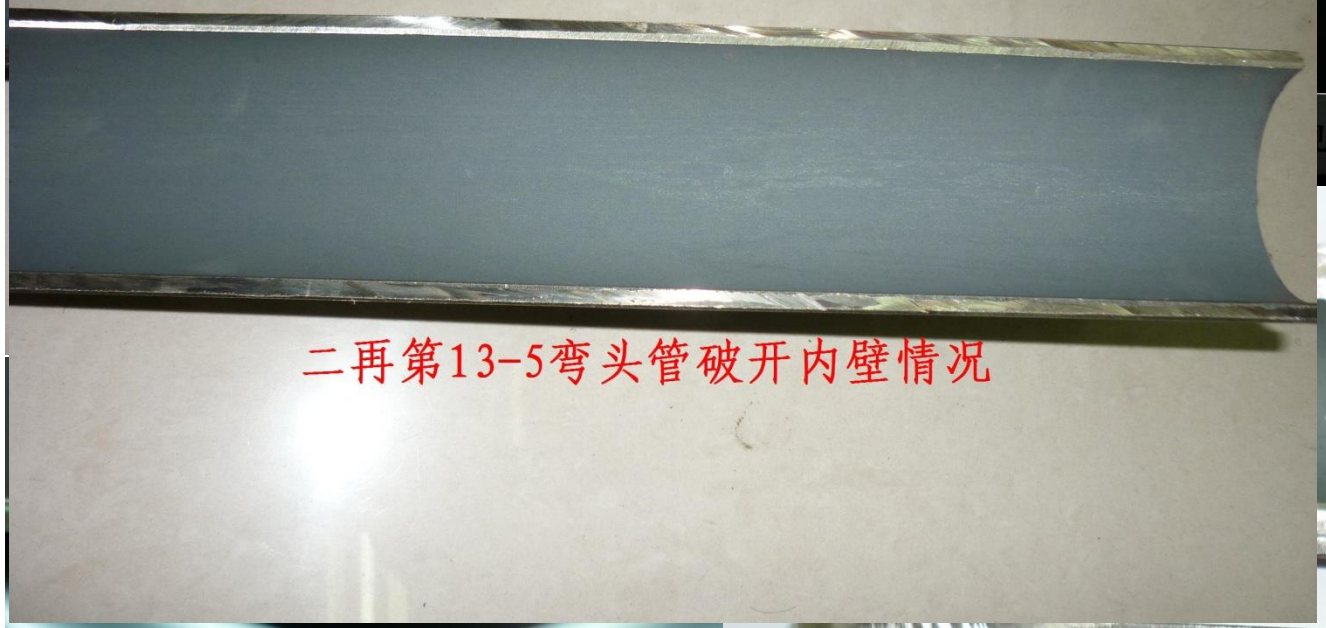
Turbine Blades Eroded by Solid Particles

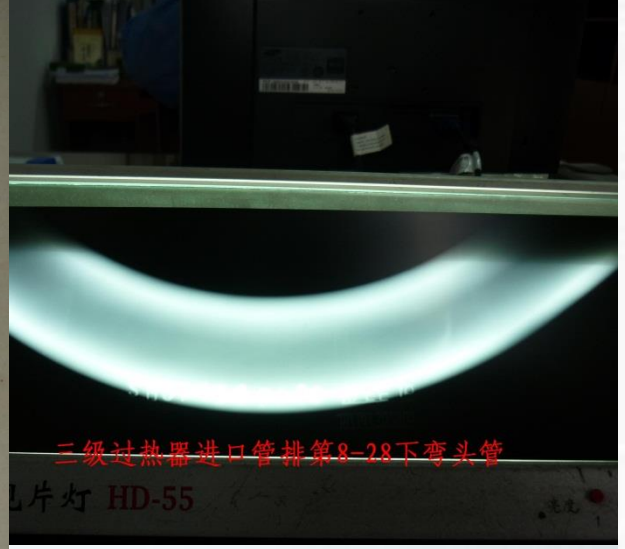


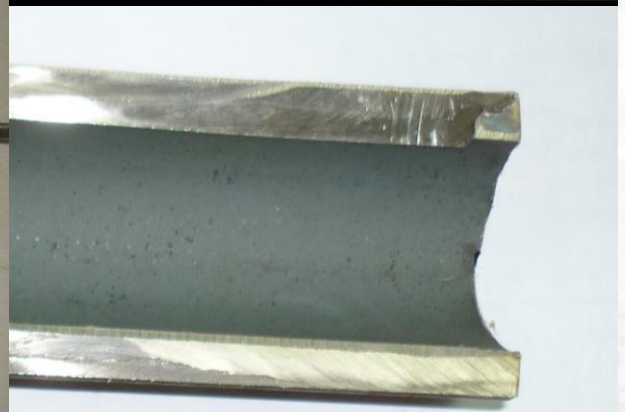
Bypass Valve Plug Eroded by Solid Particles

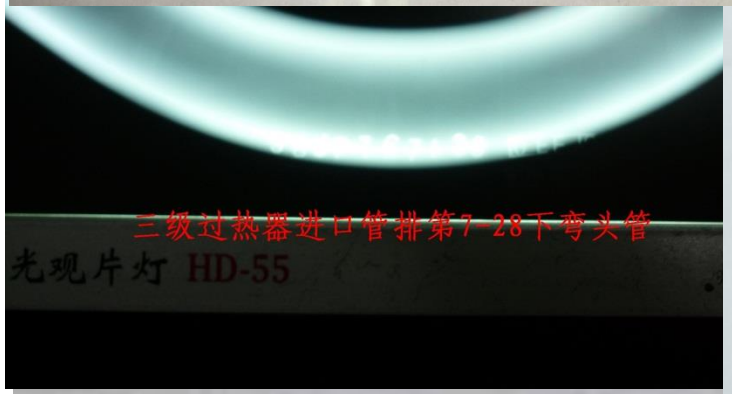
The boiler tubes of Waigaoqiao III after 60 months running

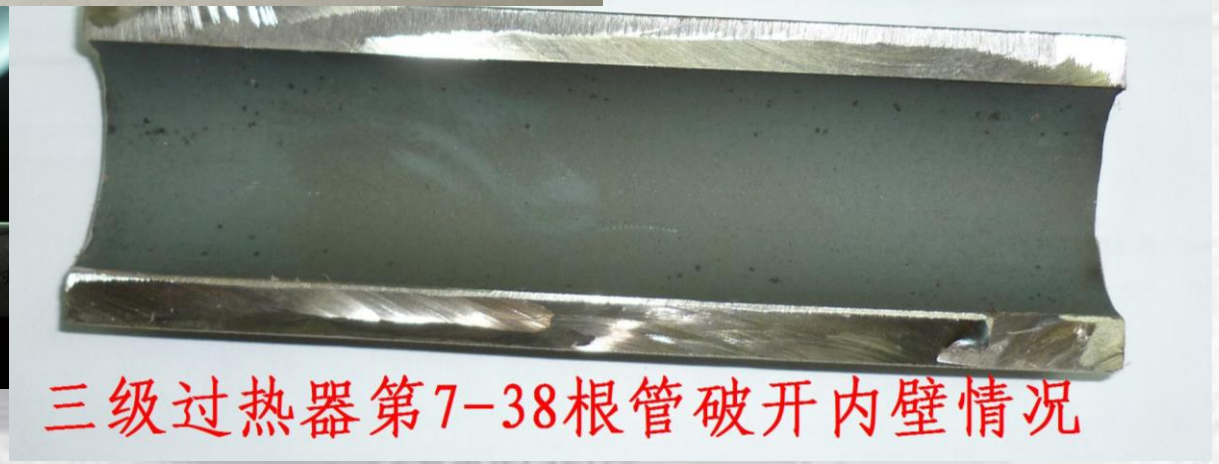
The inside of reheater tubes











WGQ3 turbine blading after 60 months operation

Performance Comparison Between Different USC Designs

Items	Conventional 1000MWe 600°C single reheat USC	Conventional 1000MWe 600°C double reheat USC	1350MWe 600°C double reheat USC with E+C layout	1350MWe 700°C double reheat USC with E+C layout
Heat rate (kJ/kWh)	7,320	7,070	**6,882**	**6,621**
House power rate (%)	4.5	3.5	3.2	3.0
Design UNE (%LHV basis)	43.5	46	**49.80(1)**	**53(2)**
Design CO_2 emission (g/kWh)	704	674	**622.69**	**588.21**
Operating UNE (%LHV basis)	<41.5	<44	**48.8**	**52**
Operating CO_2 emission (g/kWh)	737.9	704.6	**635.4**	**599.5**

Remarks:

(1) After optimization of parameters, the heat rate of 1,350MW USC is reduced from 6,947 kJ/kWh to 6,882 kJ/kWh， therefore, the unit net efficiency without Feng's 4E technologies will be from 47.1% up to 47.5% . In addition, due to the use of Feng's 4E technologies for 1350MW project, the efficiency increment will be further improved from 1.82% to 2.3%, which results in the increase of unit net efficiency from 48.92% to **49.8% LHV basis**.

(3) Unit net efficiency 53% is based on 700°C material and Feng's 5E technologies.

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Conclusions -- Demonstration of Pingshan Phase II project

- **Using existing mature 600℃ materials and equipment in a double reheat design, the UNE under rated condition is expected to reach 49.8% (LHV) with Feng's 5E technologies. The annual average operating UNE can be as high as 48.8%. The corresponding CO_2 gross emissions is 635g/kWh, lower than the EPA standard.**

- **The Pingshan phase II project plans to begin construction in 2017. This unit, as the most efficient and cleanest coal-fired unit in the world, will be put into operation around the end of 2019.**

- **Once the 700℃ materials become more mature, the unit design net efficiency can be further improved to 53% (LHV). In fact, the Elevated and Conventional layout design is very likely to become the only economically feasible choice in view of the great cost of 700℃ materials**

Outlook

➢ New built -- Medium capacity double reheat with elevated layout

- 660MW, half of Pingshan Phase II, more flexible in capacity
- Application of Feng's 5E, UNE close to that of Pingshan Phase II
- An ongoing project in Fuyang (Anhui), building 2*660MW units

➢ Existing -- Innovative retrofit technologies of subcritical units

- Expect to improve UNE from about 34%~37% to as high as 41%~43%, much higher than UNE of Supercritical units
- Excellent performance on investment return
- An ongoing project in Xuzhou (Jiangsu) and more upcoming projects

Outlook

- In September and December of 2016, experts from USA DOE and senior think tank have visited Prof. Feng and Waigaoqiao No.3 plant to learn more about Feng's 5E technologies

- The clean coal power route of the USA: New built units – Elevated and Conventional layout double reheat units with Feng's 5E technologies; Existing subcritical units – High temperature subcritical retrofit combined with other technologies

- It's our common target for global warming prevention and environmental protection. We are willing to work hard together with our counterparts from all over the world for a more efficient and more clean power generation industry.

Thank you for your attention !