中国 700℃超超临界燃煤发电关键部件验证试验平台建立及运行

China's Key Component Test Facility of 700℃ Advanced Ultra-supercritical Coal-fired Power Generation Unit

中国华能集团清洁能源技术研究院
Huaneng Clean Energy Research Institute
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2017-11-30

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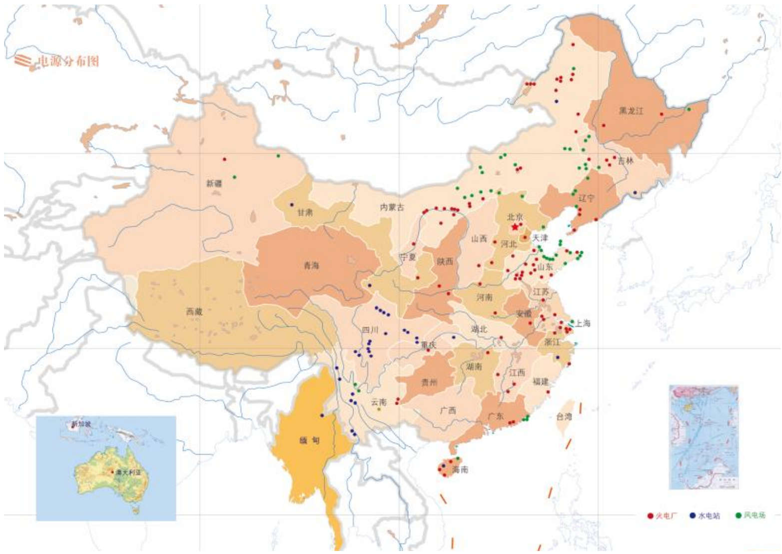
华能集团简介China Huaneng Group

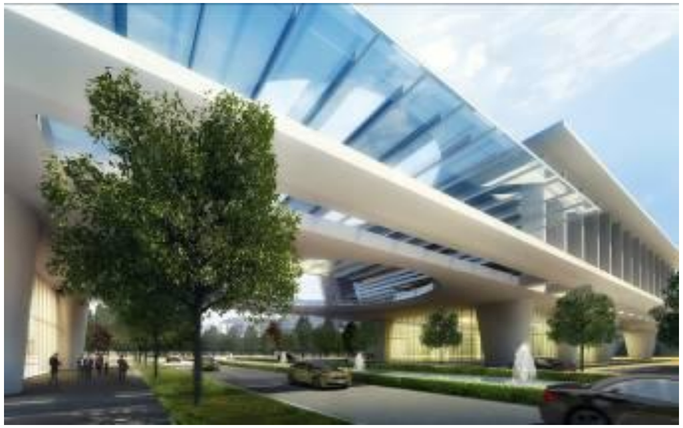


- 国务院批准成立的国有重要骨干企业
- Key state-owned company established with the approval of the State Council
- 全球装机规模最大的发电企业
- The largest power generation company in the world
- 截至2016年底，公司境内外全资及控股电厂装机容量达到1.6554亿千瓦
- By the end of 2016, had total installed capacity of 165.54GW, with assets distributed in China and overseas
- 中国发电企业中率先进入世界500强
- The first Chinese power producer to join the ranks of Fortune 500 Companies, ranking 217th in 2016
- 积极发展清洁煤发电，加速发展新能源
- Actively develop clean coal power and accelerate the development of new energy

华能清能院简介Introduction to CERI

- 定位：中国华能集团直属清洁能源前沿技术研发机构
- **Institution focused on the frontier technology research and development of clean energy**
- 研发方向Mainly focuses on research of the following aspects:

近零排放燃煤发电	Nearly zero emission for coal-fired power generation;
煤气化及煤基清洁转化	Coal gasification and clean coal-based energy conversion;
CO2捕集、利用和封存	Capture, utilization and storage of CO_2;
大型循环流化床锅炉	Large–scale circulating fluidized bed boiler;
低质煤利用	Low-quality coal utilization;
可再生能源发电	Renewable energy power generation;
能源系统设计优化	Design and optimization of energy system.



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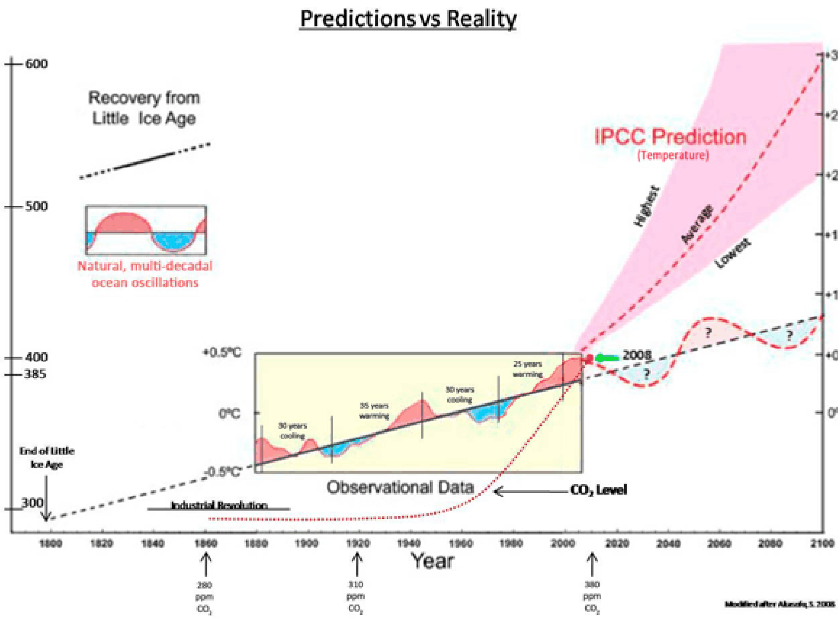
700℃ 发电技术 700℃ USC Coal-fired Power Generation

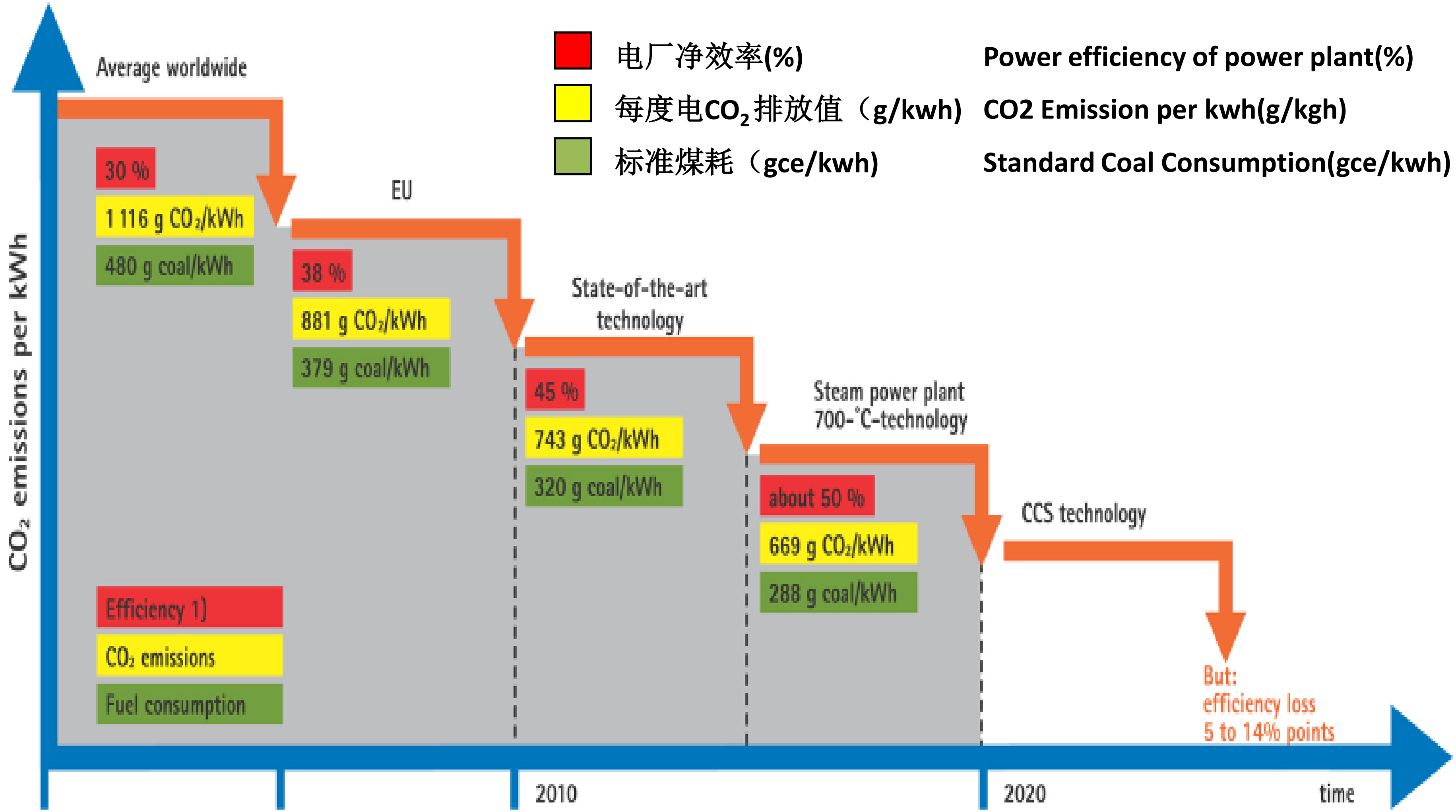


目前，大多数学者和国家都支持全球变暖与人类活动产生的CO_2关系密切的观点

Most scholars and nations support the theory of deep correlation between global warming and human activities

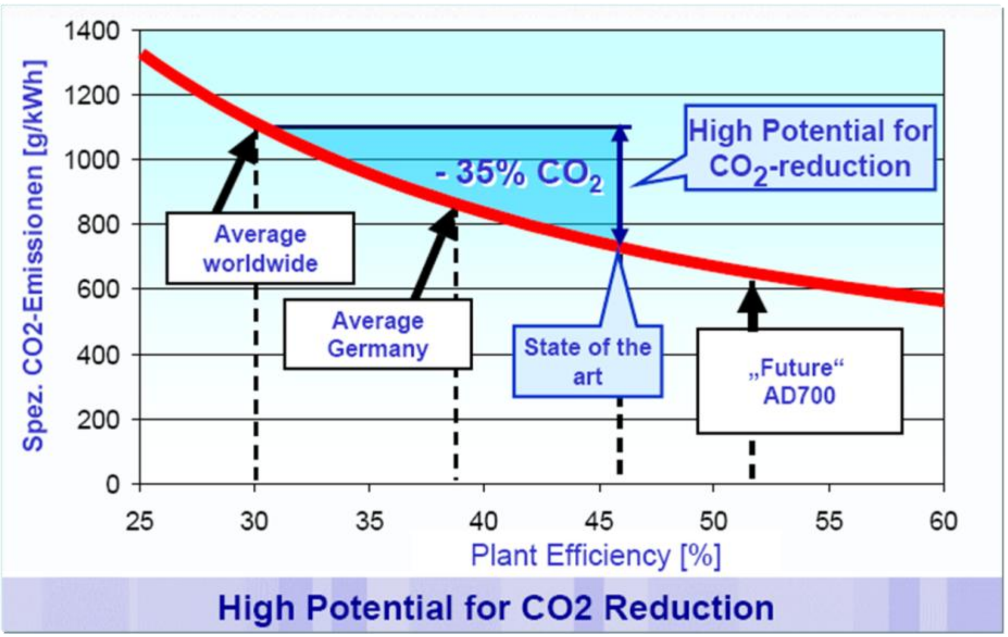
华能清洁能源研究院
HUANENG CLEAN ENERGY RESEARCH INSTITUTE

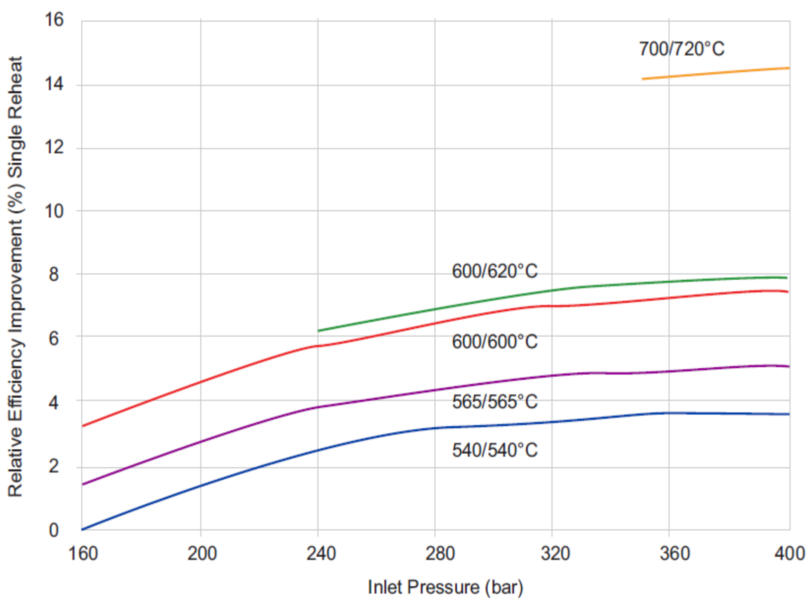
CO_2减排潜力及可能进度 The potential of CO_2 reduction



1) Average data for hard coal-fired power plants

700℃ 发电技术 700℃ USC Coal-fired Power Generation





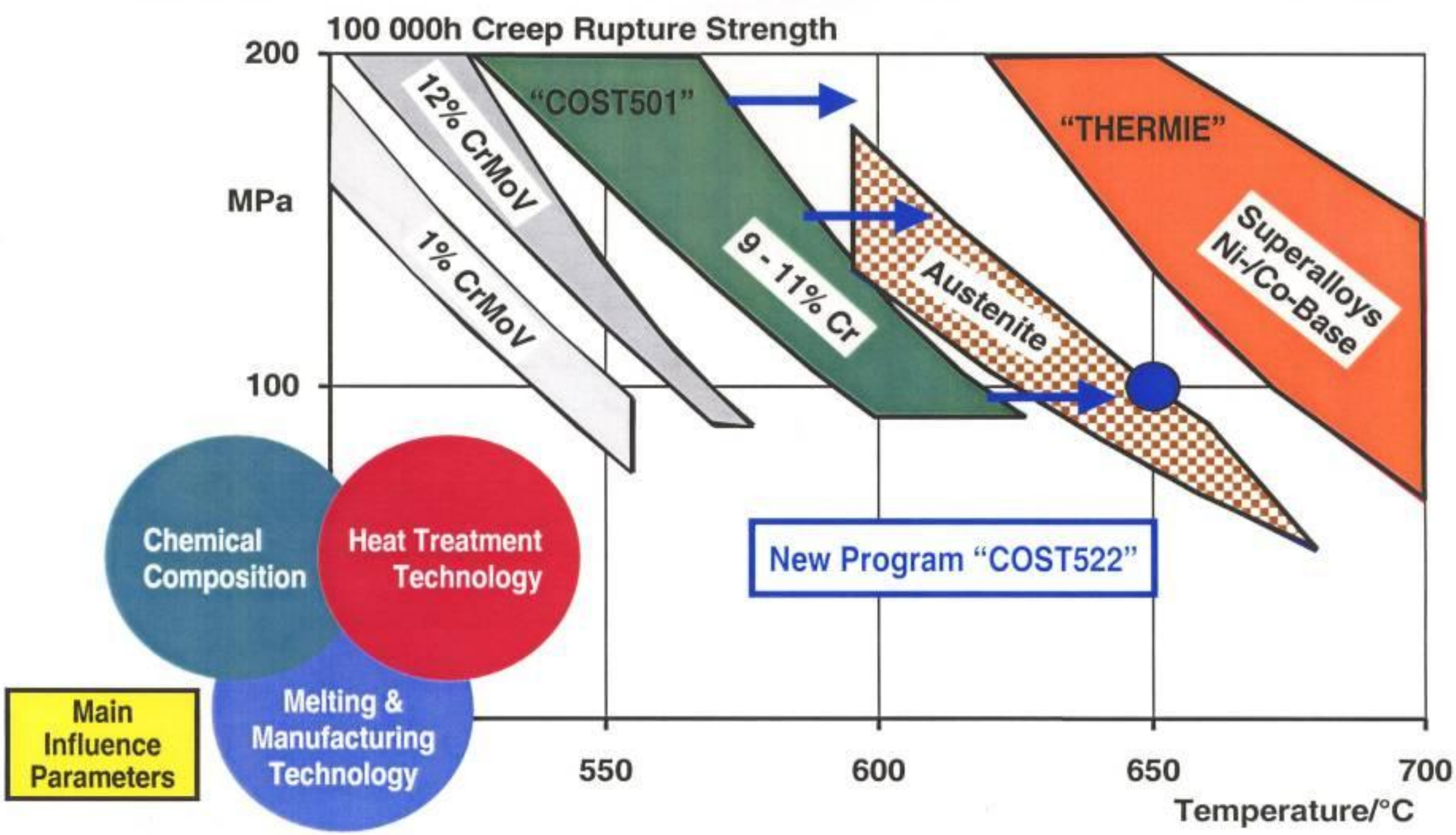
主汽温度提高到 700℃以上，机组效率大幅提升，有效降低CO_2排放

By increasing the temperature of inlet steam above 700℃, power efficiency can be greatly increased, also CO_2 emission can be reduced

700℃ 发电技术 700℃ USC Coal-fired Power Generation

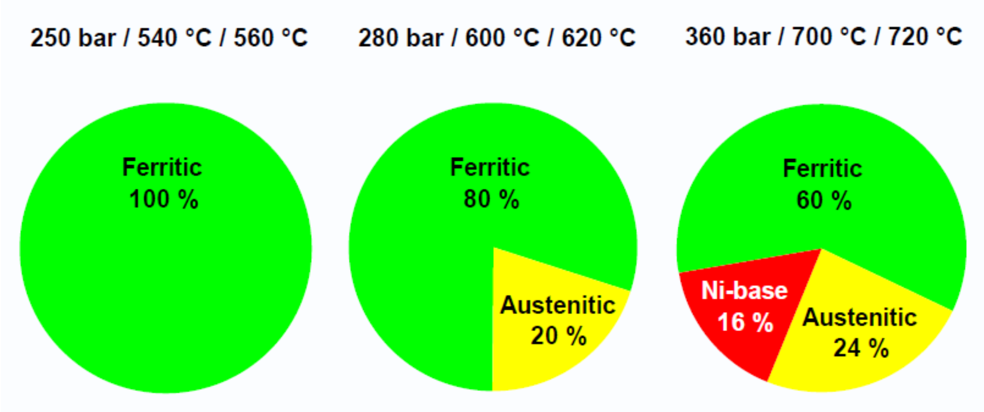
耐高温合金材料筛选与研发是700℃研制的关键

The sift and R&D of high temperature alloy is the key to 700℃ project



700℃ 发电技术 700℃ USC Coal-fired Power Generation

- 需要对将大量使用的镍基高温合金材料进行研究、验证、完善
- Nickel Alloy Material needs a lot of study\verify\improvement
- 700 ℃ 主要候选材料： Inconel 617、Inconel 740、Haynes 282等
- Main Candidate: Inconel 617、Inconel 740、Haynes 282 etc



- 欧洲于1998年启动了AD700计划，先后建立了Esbjerg、COMTES700、 GKM HWT I/II等关键部件验证试验平台，对高温合金材料和关键部件进行实炉验证，积累生产制造加工的经验，降低建立700℃先进超超临界工业示范电站的成本和风险
- Europe has started the AD700 project in 1998, and has built key component testing platform, such as Esbjerg, COMTES700, GKM HWT I/II, to field test high temperature alloy and key component, gain experience on processing tech, decrease cost and risk in building 700℃ advanced USC industrial testing power plant

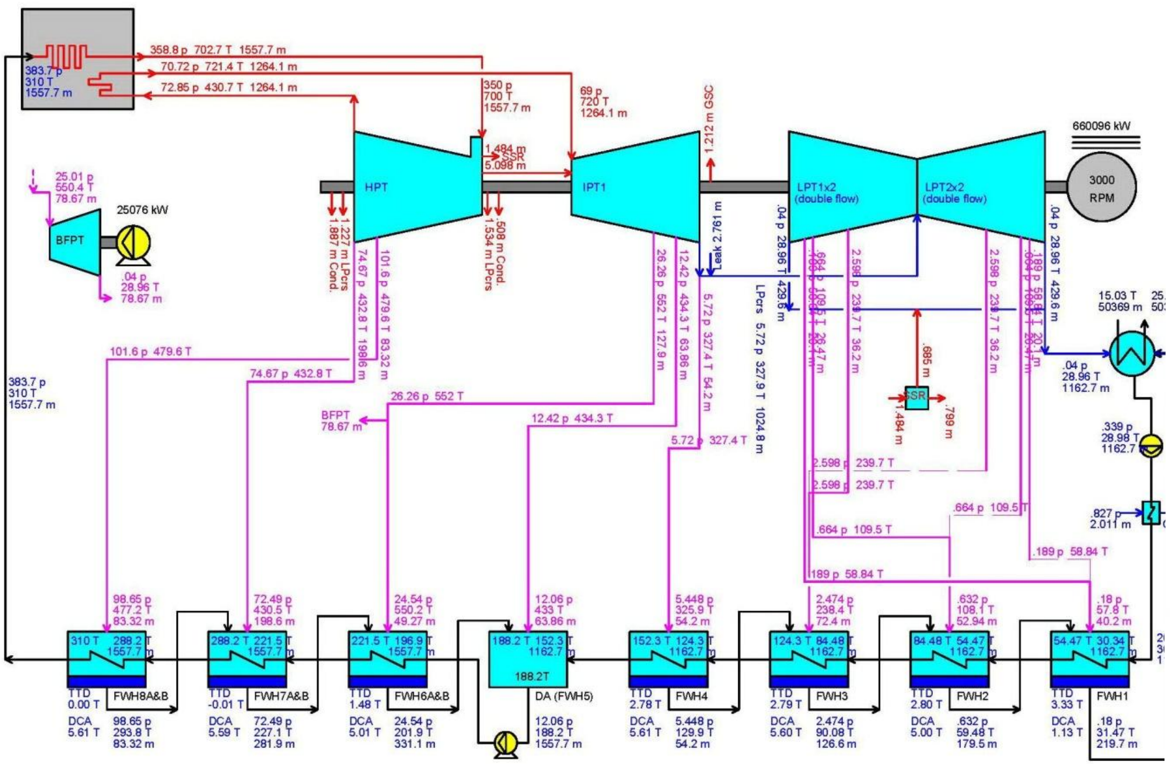
700℃ 发电技术 700℃ USC Coal-fired Power Generation

	欧洲 European“AD700”	美国American USC	日本Japanese “A-USC”
项目 Project	Advanced AD700 Supercritical tech	Advanced USC Supercritical Power Generation tech	Advanced A-USC Supercritical Power Generation tech
发展目标 Goal	500MW 37.5MPa/705℃/720℃ Unit net power efficiency ≈ 50% (LHV)	750MW 37.9MPa/732℃/760℃ Unit net power efficiency ≈ 45% ～47%	650MW 35MPa/700℃/720℃ Unit net power efficiency ≈ 46%
计划时间表 Schedule	1998-2003：Main Design and feasibility study 2002-2005：Boler and Turbine Design 2004-2008：Unit Test 2008-2014：Power Plant Test and launch operation	2001-2006：First Phase Material Study 2006-2007：Second Phase Deep down Study (Including Pure Oxygen Burning Implementation) 2008-2015：750MW Test Power Plant	Before 2008: First and Second Phase of Material Study (Done) 2008-2012：Technical Study of Boiler\Turbine\Valve, Long test of Material 2012-2016：Material Test, Turbine Test
主要任务 Main Task	Feasibility Study \ Material Study \ Power Plant Design(Boiler Turbine Design Optimization) \ Test Project building and launching	Efficiency and feasibility Study \ Material Study(Boiler, Turbine Material) \ Power Plant Design(Boiler, Turbine Design Optimization)	Efficiency and feasibility Study \ Material Study \ Boiler Design Optimization, Turbine related Tech Study \ High pressure turbine test
目前状态 Status Quo	Main Component field test, slowed down by energy policy and R&D funds	Phase 2 completed, affected by shale gas revolution and lack of funds	Phase 2 completed, Long Term Material Test, Manufacture Tech

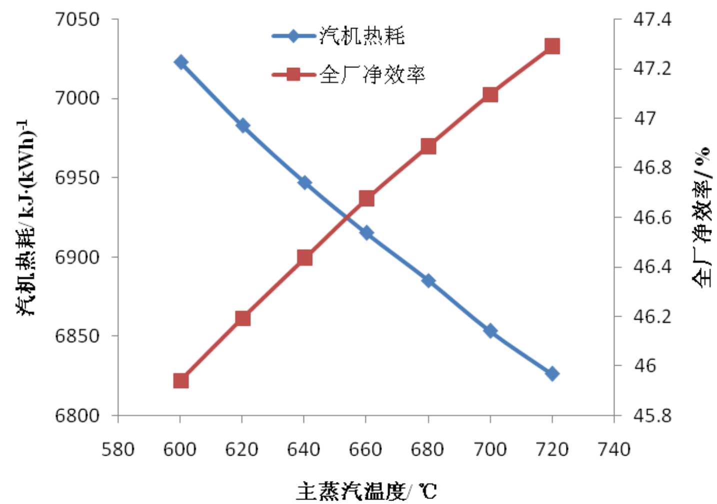
700℃机组关键参数优化 Optimization of Key Parameter

华能清能院开展700℃机组参数及容量优选研究

CERI Research on 700℃ Unit Parameter and capacity Optimization



汽水系统计算 calculation of water-steam system

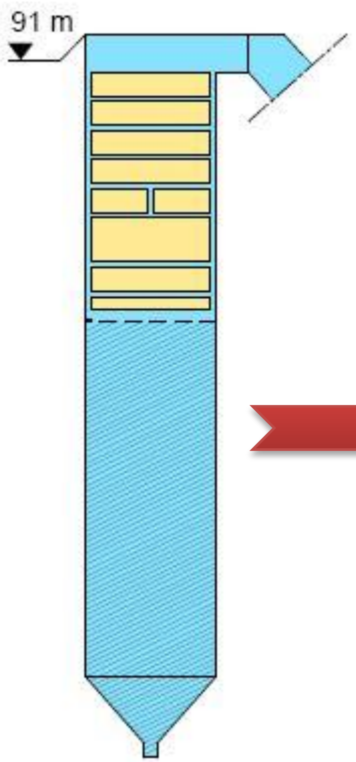


汽机热耗、全厂净效率与主蒸汽温度关系

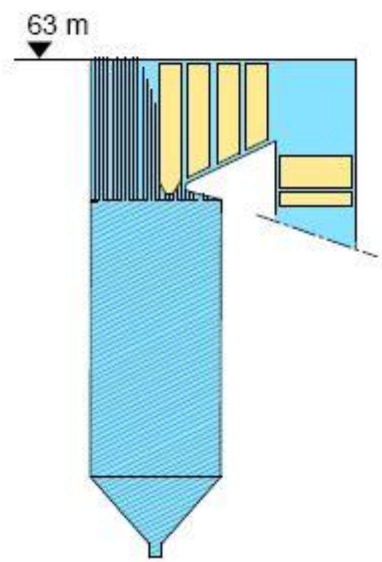
Correlation Between Steam Turbine heat rate, net efficiency and main steam temperature

700℃新型炉型紧凑布置研究 Unit compact design

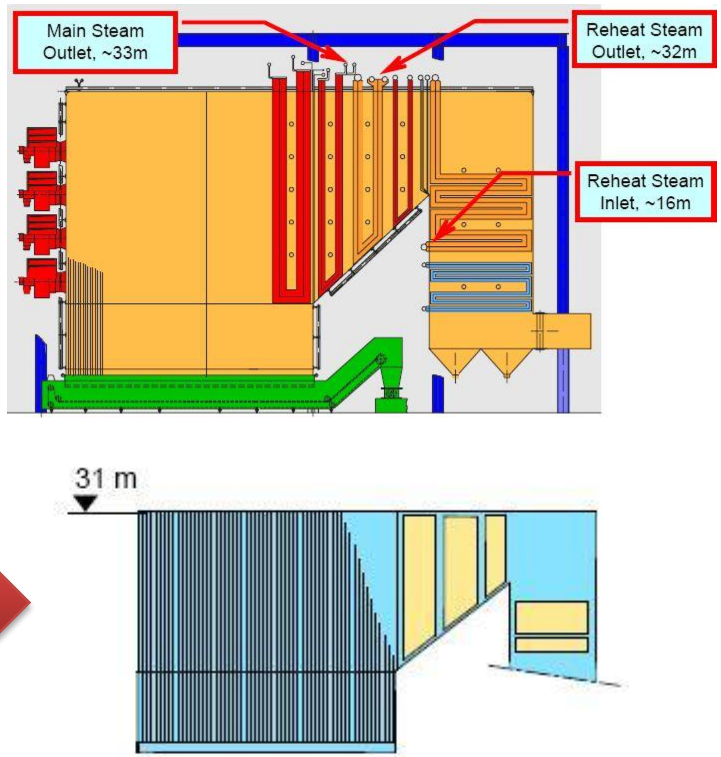
550MWe 不同布置直流锅炉高度比较
Comparison of the height of different boilers



塔式炉tower boiler



П型炉 П type boiler

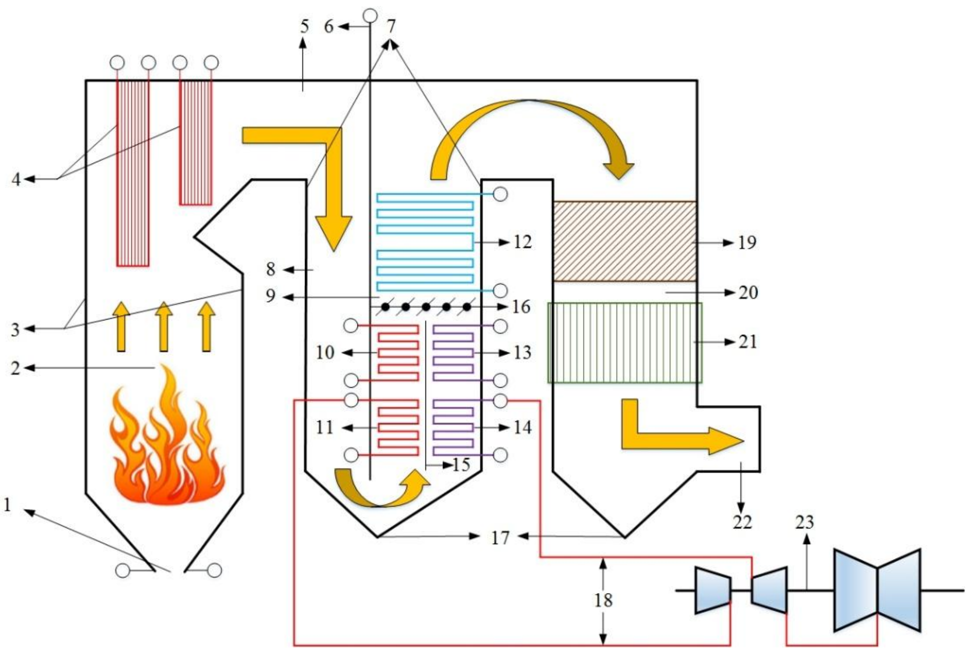


卧式炉 horizontal type boiler

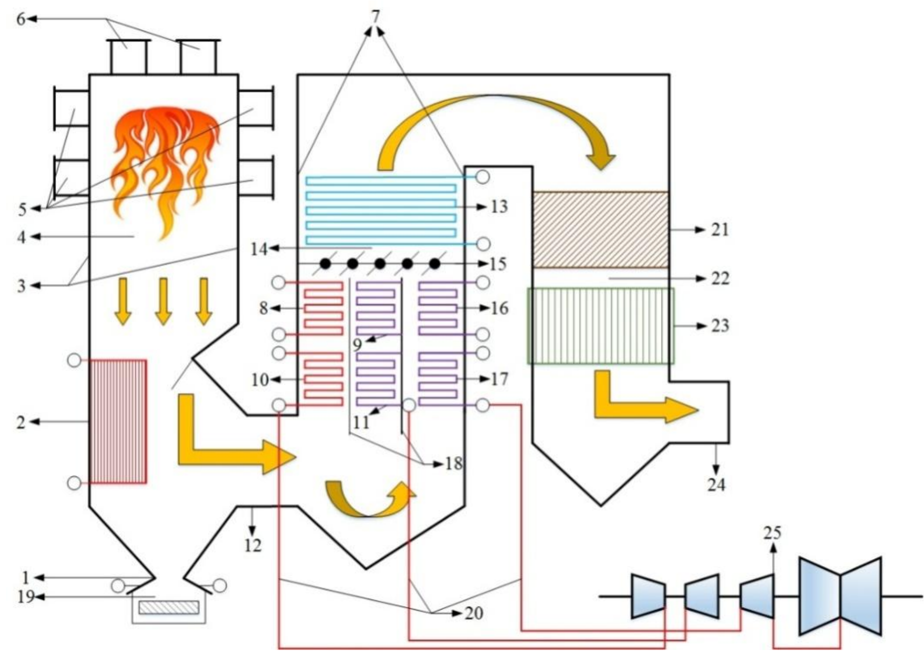
700℃新型炉型紧凑布置研究 Unit compact design

华能清能院提出两种新型700℃超超临界燃煤锅炉布置形式，实现机组紧凑设计，减少镍基材料用量，已获中国发明和美国发明专利授权

CERI has come up with two new designs for 700℃ Ultra-supercritical coal-fired boilers, which result in compact unit design and less usage of Nickel-based material. These Designs have been granted Chinese and US patents.



M型锅炉布置形式 M-type boiler



倒置型锅炉布置形式 Arrangement structure boiler

700℃新型炉型紧凑布置研究 Unit compact design

- M型锅炉初步设计特点 The characteristics of M-type boiler design
  - ✓ 缩短镍基管道长度
  - ✓ 炉膛及过渡烟道无受热面，燃尽好
  - ✓ 对流受热面集中布置于尾部烟道
  - ✓ Shorten the length of Nickel tube
  - ✓ Furnace and middle flue without heating surface, to assist burning
  - ✓ All convection heating surface arrange in the tail flue
  - ✓ 侧墙对冲燃烧，便于低NOx燃烧
  - ✓ 无屏式过热器，避免氧化皮脱落
  - ✓ 对流受热面烟气向上，磨损轻
  - ✓ Side wall opposed firing, improve low NOx
  - ✓ Without platen superheater, to prevent boiler oxide skin shedding
  - ✓ Flue gas flow upwards through convection heating surface to decrease wear
- 新炉型结合材料部件国产化，700℃机组造价可望降至4555元/千瓦
- Economical analysis shows, the new design combined with manufacturing material and component domestically, can reduce 700℃ unit building cost to 4555 yuan/kw

项目名称 Item	常规600℃机组 Normal 600℃	常规700℃机组 Normal 700℃	紧凑型700℃机组 Compact 700℃	国产紧凑700℃ Domestic compact
总投资Total cost（单位：亿元）	22.2	39.13	35.41	30.06
单位造价Unit cost（单位：元/千瓦）	3367	5929	5365	4555

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我国700℃验证试验平台China’s component test facility

国家能源局2011年设立了国家能源应用技术研究及工程示范项目“700℃超超临界燃煤发电关键设备研发及应用示范”，华能清能院承担了课题五“关键部件验证试验平台建立及运行”National Energy Bureau set up national key energy project “The development and application of key component of 700℃ USC coal-fired power generation”, CERI undertook sub-project 5 ”The building / operation of key component test facility”

华能国际电力股份有限公司
HUANENG POWER INTERNATIONAL,INC.

中国华能集团清洁能源技术研究院有限公司
CHINA HUANENG CLEAN ENERGY RESEARCH INSTITUTE

上海电气
SHANGHAI ELECTRIC

中国电力工程顾问集团中南电力设计院
CSEPDI Central Southern China Electric Power Design Institute of China Power Engineering Consulting Group Corporation

哈电集团
哈尔滨锅炉厂有限责任公司
HARBIN BOILER COMPANY LIMITED

DEC 东方电气
东方锅炉股份有限公司
DONGFANG BOILER GROUP CO., LTD.

TPRI 西安热工研究院有限公司
Xi'an Thermal Power Research Institute Co., Ltd.

NWPCS
西北电力建设工程监理有限责任公司
Northwest Power Construction Supervision Ltd

BAOSTEEL 宝钢特钢

TISCO 山西太钢不锈钢股份有限公司
SHANXI TAIGANG STAINLESS STEEL CO.,LTD.

IMR 中国科学院金属研究所
INSTITUTE OF METAL RESEARCH,CHINESE ACADEMY OF SCIENCES

SPECIAL METALS A PCC Company

HAYNES International

SALZGITTER MANNESMANN STAINLESS TUBES
A Member of the Salzgitter Group

SANDVIK

IMI Critical Engineering

PENTAIR

HP VALVES

CEEC 中国能源建设集团江苏省电力建设第一工程有限公司
China Energy Engineering Group Jiangsu No.1 Electric Power Construction Co.,Ltd

CEEC 江苏电力装备有限公司

BEIYE
北京北冶功能材料有限公司
Beijing Beiye Functional Materials Corporation

上海昌强电站配件有限公司
Shanghai ChangQiang Power Co.,Ltd.

NARI 国电南瑞 NARI-TECH
北京国电富通科技发展有限责任公司
BEIJING GUODIAN FUTONG SCIENCE AND TECHNOLOGY DEVELOPMENT CO.,LTD.

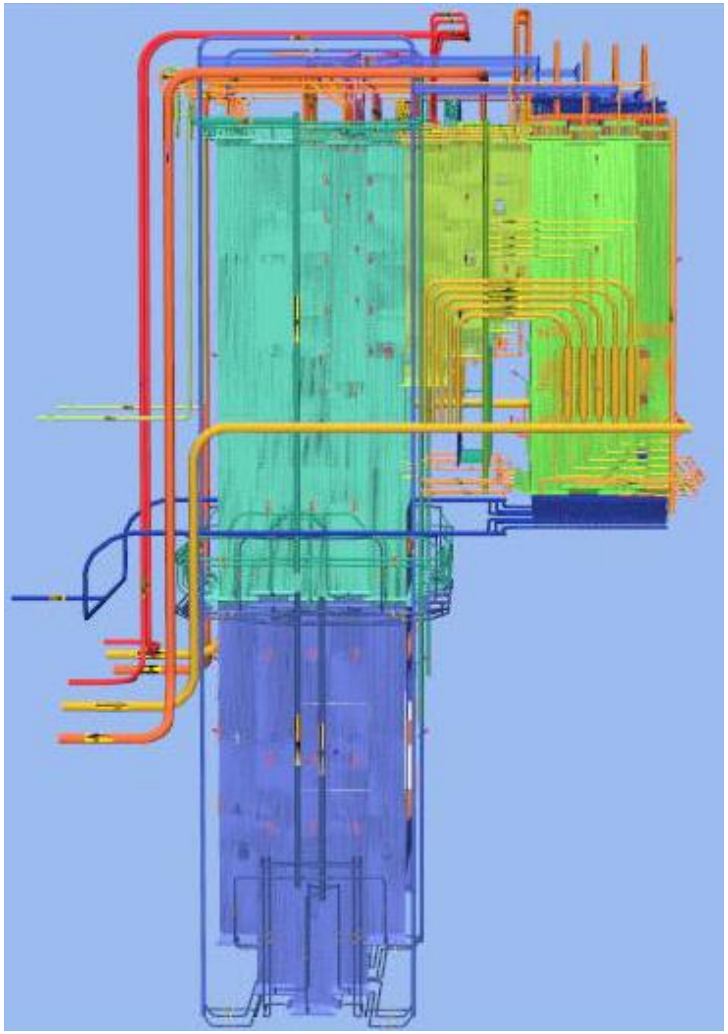
我国700℃验证试验平台China's component test facility

- **目标 Goal**
  - ➢ 在宿主机组建立一套接近于未来商业应用设计的700℃试验平台
  - ➢ 通过长周期运行，测试高温合金材料和部件的性能和可靠性
  - ➢ 掌握高温合金材料的运行经验，降低示范电厂的风险
  - ➢ Build a near-commercial applicable 700℃ testing platform in host units
  - ➢ Test the performance and reliability of high temperature alloy material and component through long term operation
  - ➢ Gain operational experience of high temperature alloy material, decrease the risk of testing power plant
- **试验平台关键验证部件 Key Testing Component**
  - ➢ 水冷试件、过热试件、集箱、大管道和附件（管件、阀门等）
  - ➢ Water-cooling component \ Overheating component \ Header \ Pipe and accessories (fitting and valves)
- **试验平台参数指标 Expected Parameter**
  - ➢ 蒸汽温度 Steam temperature ≥700 ℃，蒸汽流量 Steam Flow ≥ 10 t/h

系统设计研究 System Design

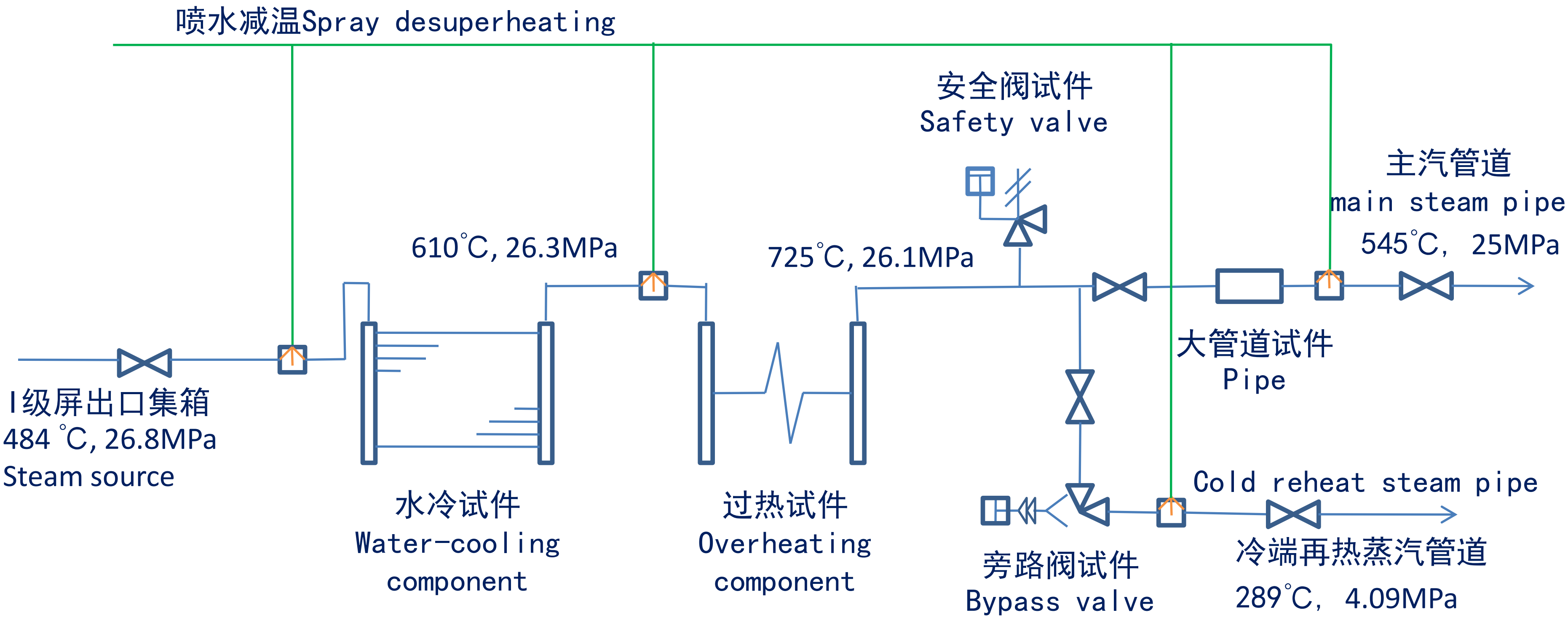
- 华能南京电厂#2机组作为我国700℃试验平台宿主机组Huaneng Nanjing Power Plant Unit 2 as Host Unit，320 MW supercritical unit，ПП-1000-25-545-KT
- 试验平台关键设计参数Key Parameters

项目 Item	单位	数值
工质质量流量flow rate	kg/s	3
工质进口压力inlet pressure	MPa	26.8
工质进口温度inlet temperature	℃	486
工质最高试验温度design temperature	℃	725
主蒸汽回路工质出口压力main outlet	MPa	25
主蒸汽回路工质出口温度main outlet	℃	545
再热蒸汽冷端工质出口压力bypass outlet	MPa	4.087
再热蒸汽冷端工质出口温度bypass outlet	℃	289.56



系统设计研究 System Design

试验平台主汽水流程图 Diagram of main water-steam flow in test facility

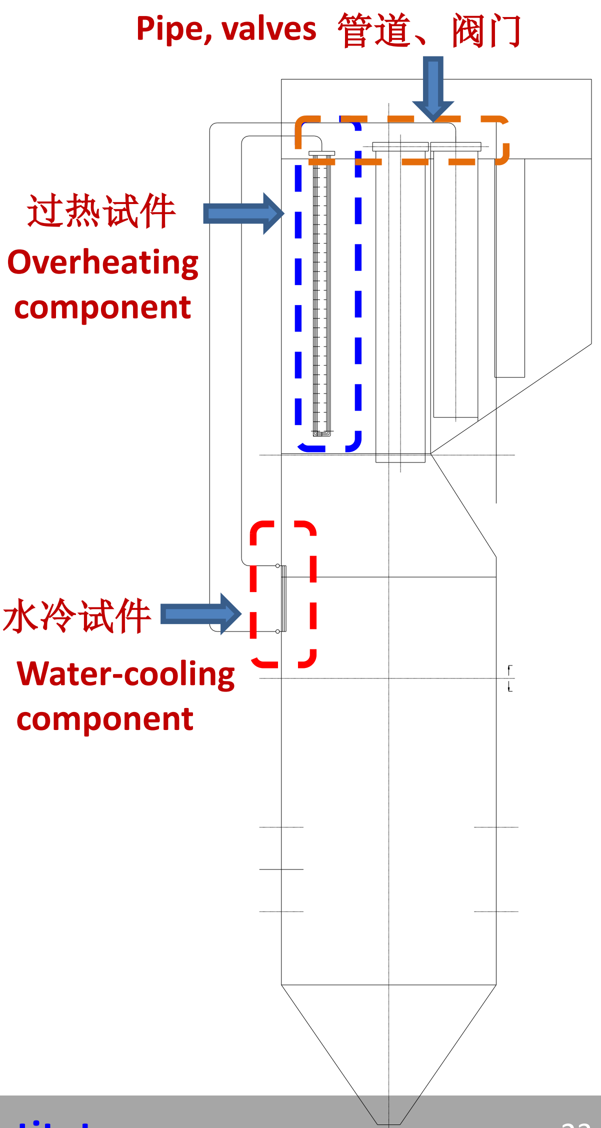


为了保证试验平台的安全稳定运行，我们还设计了临炉保护蒸汽、备用汽源、备用旁路等。In order to ensure the secure and stable operation of test facility, we also designed side protection steam , backup steam source, backup bypass etc.

施工设计研究 Detail Design

试验平台现场布置 Field layout

- 水冷试件Water-cooling component： 布置在炉膛前墙，上辐射区下部 front wall of furnace, lower parts of up-radiation area;
- 过热试件Overheating component： 布置在炉膛上炉膛前部front parts of furnace;
- 大管道试件Pipe component： 布置在炉顶平台Boiler roof platform;
- 主蒸汽阀、旁路阀、安全阀Valve component： 布置在炉顶平台Boiler roof platform.



施工设计研究 Detail Design

水冷试件的设计 Design of Water-cooling component

管屏数量number of tube panels : 1

管子数量number of tubes: 11

管屏形式tube panel layout : U型 U-shape

管子规格size of tubes: 33.7×7.1 mm

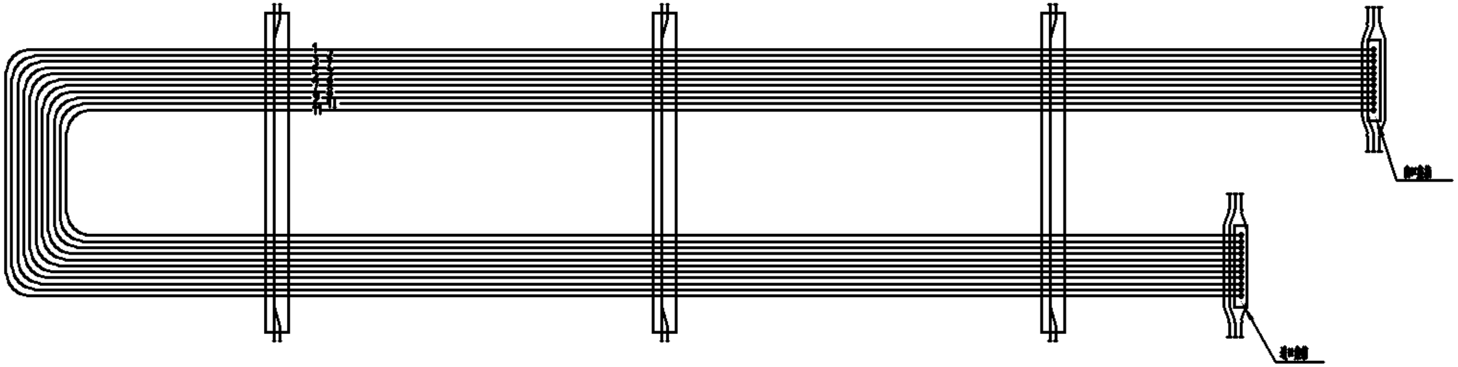
出口压力outlet pressure : 26.2 Mpa

出口温度outlet temperature: 610℃

设计试验材料Designed testing material : P91、617B、GH984G、C-HRA-3

入口集箱inlet header: P91

出口集箱outlet header : P92



施工设计研究 Detail Design

过热试件的设计 Design of Overheating component

管屏数量number of tube panels: 2

管屏形式tube panel layout: U型 U-shape

管子数量number of tubes : 4×2

管子规格size of tubes : 44.5×10 mm

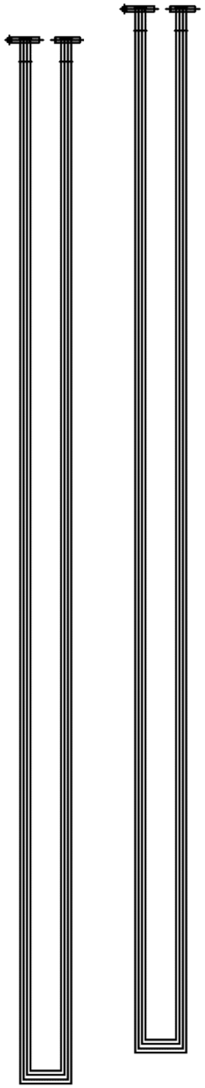
出口压力outlet pressure: 25.8 MPa

出口温度outlet temperature : 725℃

设计试验材料Designed testing material : Sanicro25、617B、740H、282、GH984G、 C-HRA-1、 C-HRA-3、TG700A、TG700B

入口集箱inlet header : P92

出口集箱outlet header : C-HRA-1



施工设计研究 Detail Design

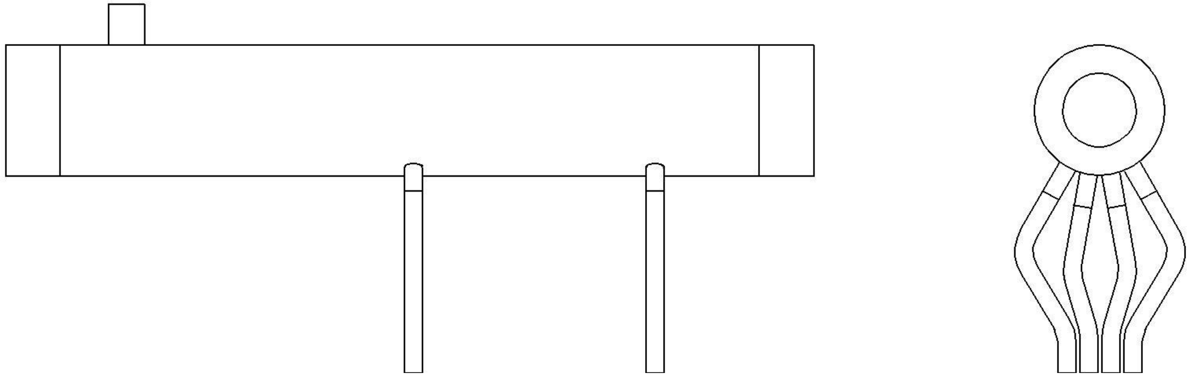
镍基集箱大管道的设计Design of nickel alloy header and pipe

蒸汽压力Steam pressure: 25.8 Mpa　　蒸汽温度Steam temperature: 725℃

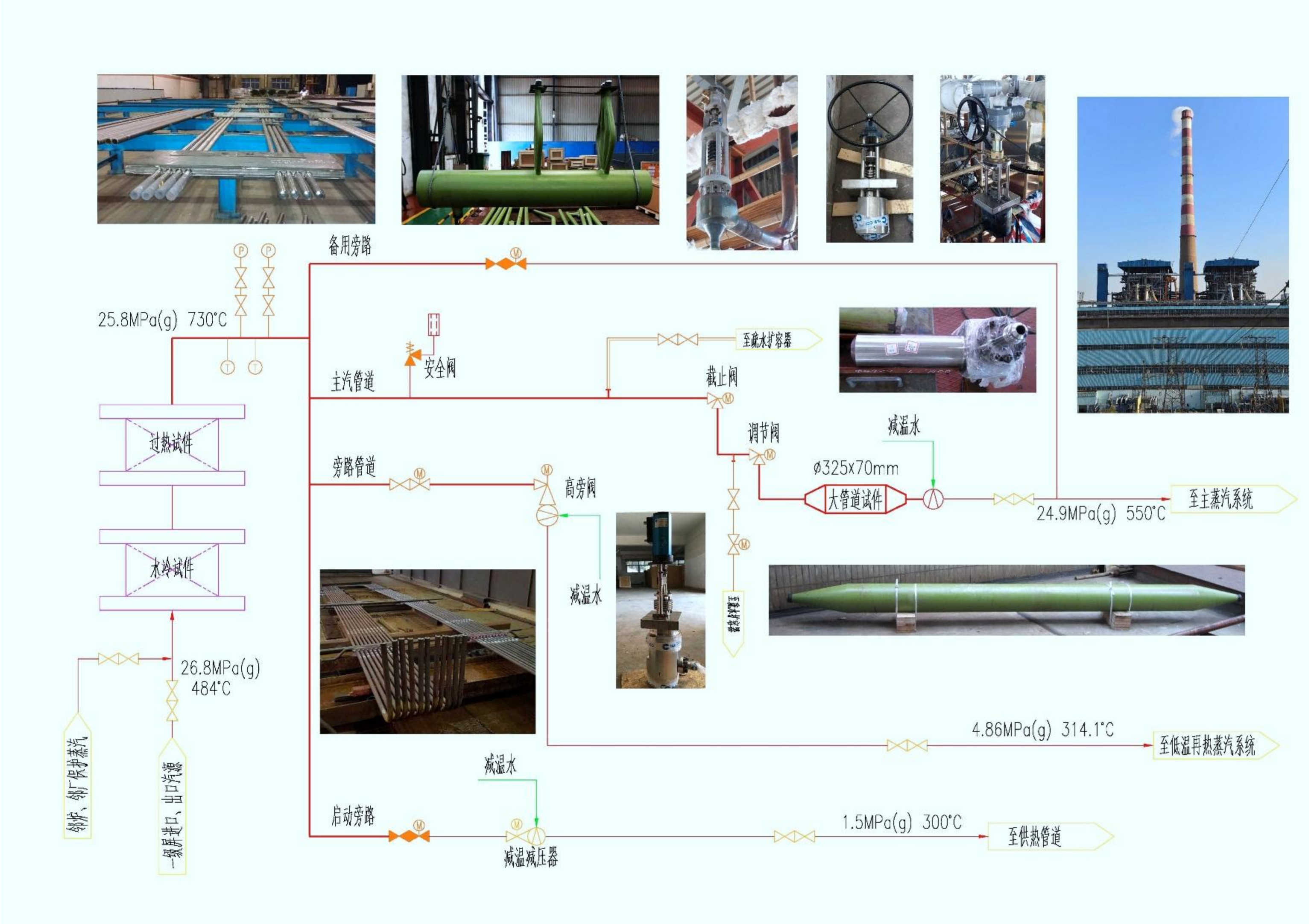
镍基集箱及大管道选用国产材料 Pipe and header material：C-HRA-1

镍基集箱有两种方案Two type of header： Φ325×70mm（主main）和 and Φ89×20mm（备backup）

大管道规格Pipe size：Φ325×70mm，长度length：4m，出口经由喷水减温器后回到主蒸汽管道 Outlet was connected by spray desuperheating device, back to main steam pipe after been cooled



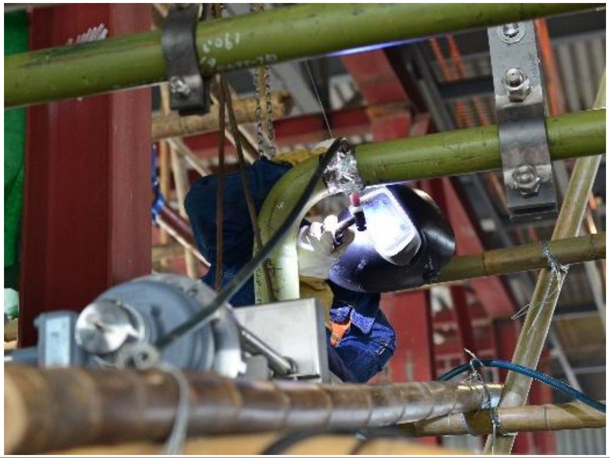
我国700℃验证试验平台China’s component test facility



建设安装研究Manufacturing and Construction Study

- 2015年11月1日开始安装→大型吊装→蒸汽管路安装→水压试验→管道冲洗→管道恢复→静态调试，至12月27日完成平台保温
- Facility construction started on Nov 11th 2015, Large hoisting completed on Dec 2nd, steam tubes completed on Dec 7th, water pressure experiment succeeded on Dec 9th, tube flushing completed on Dec 16th, tubes restoration completed on Dec 20th, static experiment completed on Dec 25th, Insulation completed on Dec 27th
- Following organization were involved to ensure quality and security

- Install: Jiangsu No.1 Electric Power Construction
- Inspection：CERI and Nanjing Power Plant
- Manufacture Supervise：TPRI
- Engineering Supervise: Northwest Electricity



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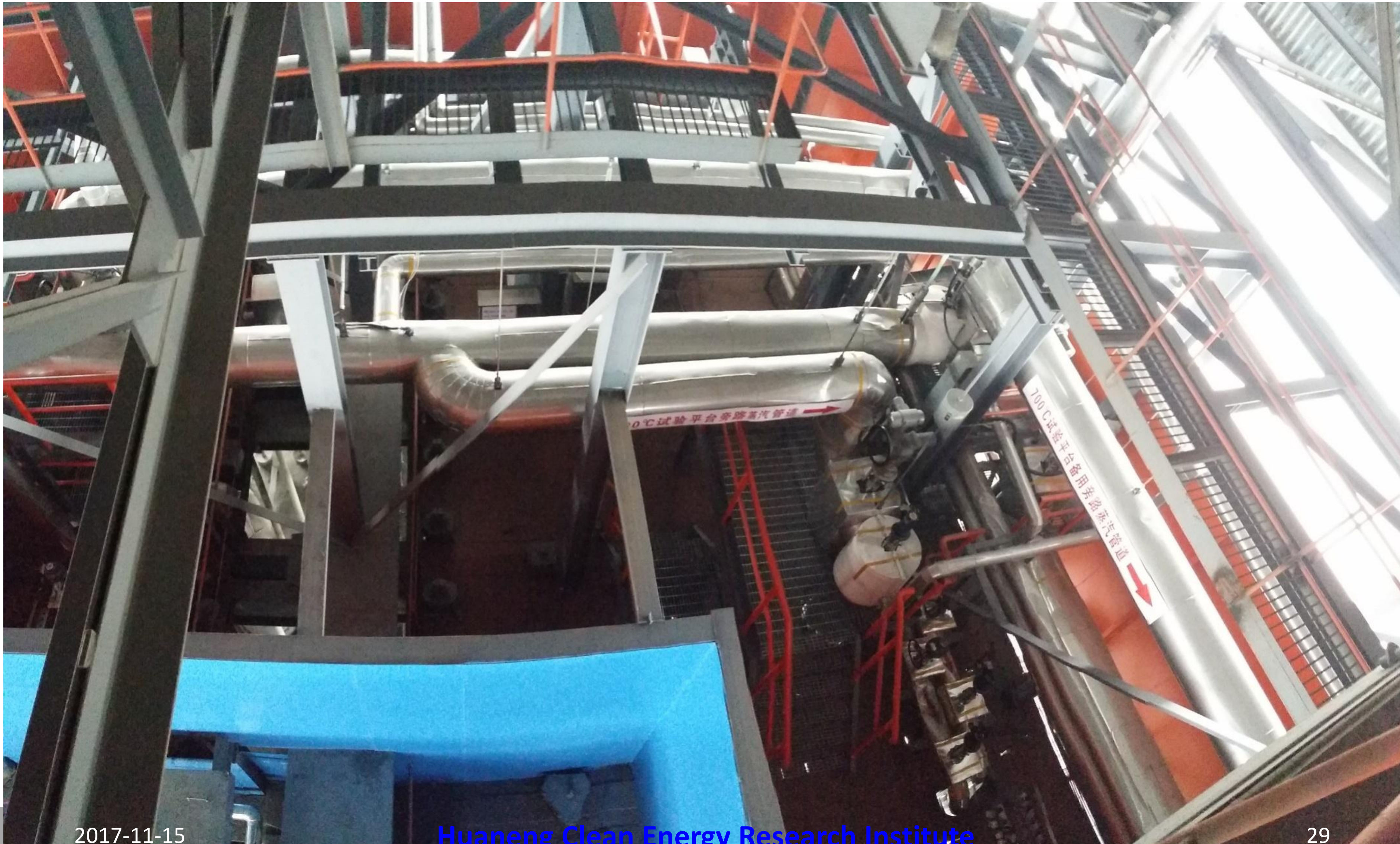
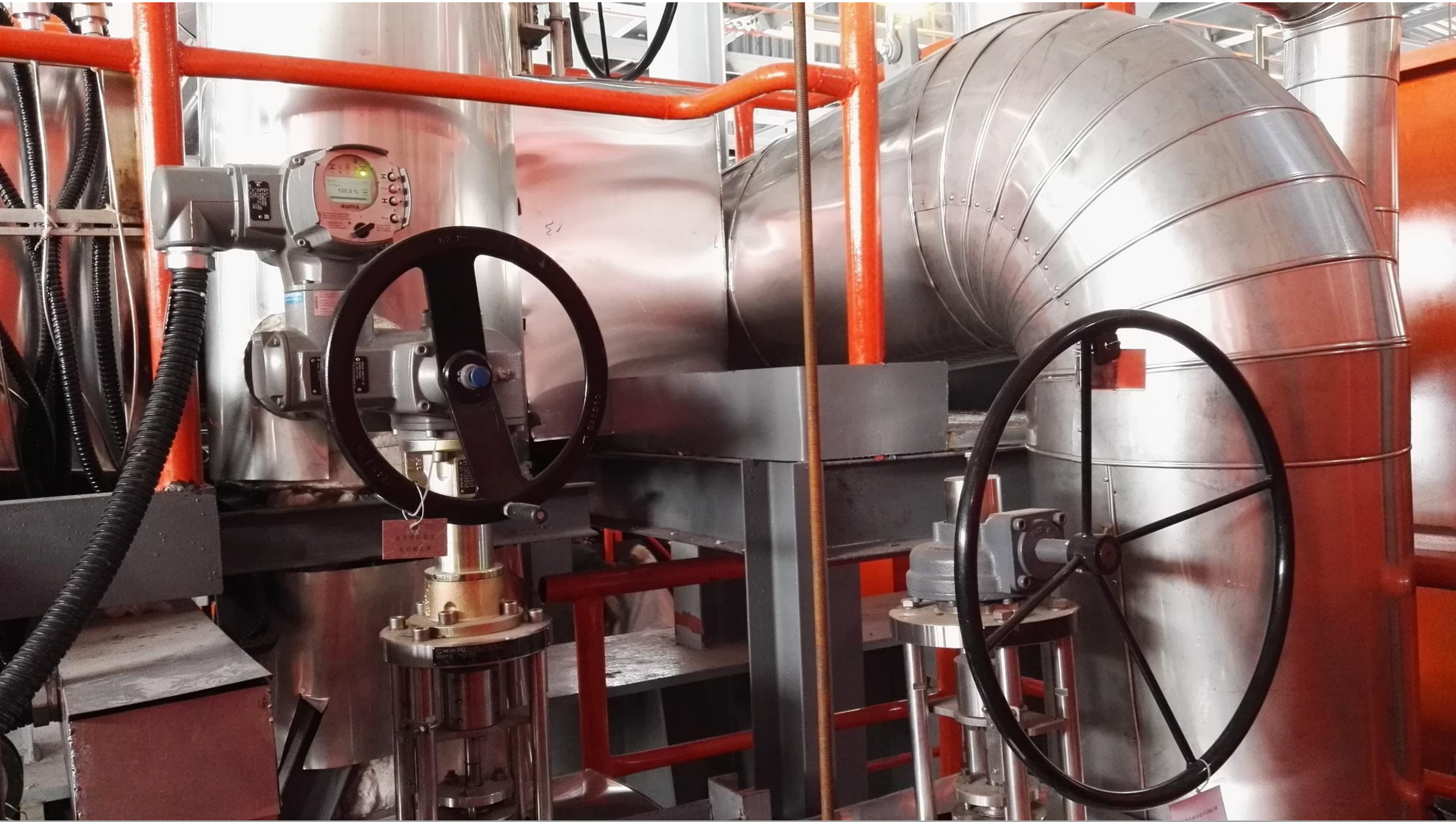


我国700℃验证试验平台China’s component test facility

华能清洁能源研究院
HUANENG CLEAN ENERGY RESEARCH INSTITUTE

我国700℃验证试验平台China's component test facility



运行试验研究Running Experiment Study

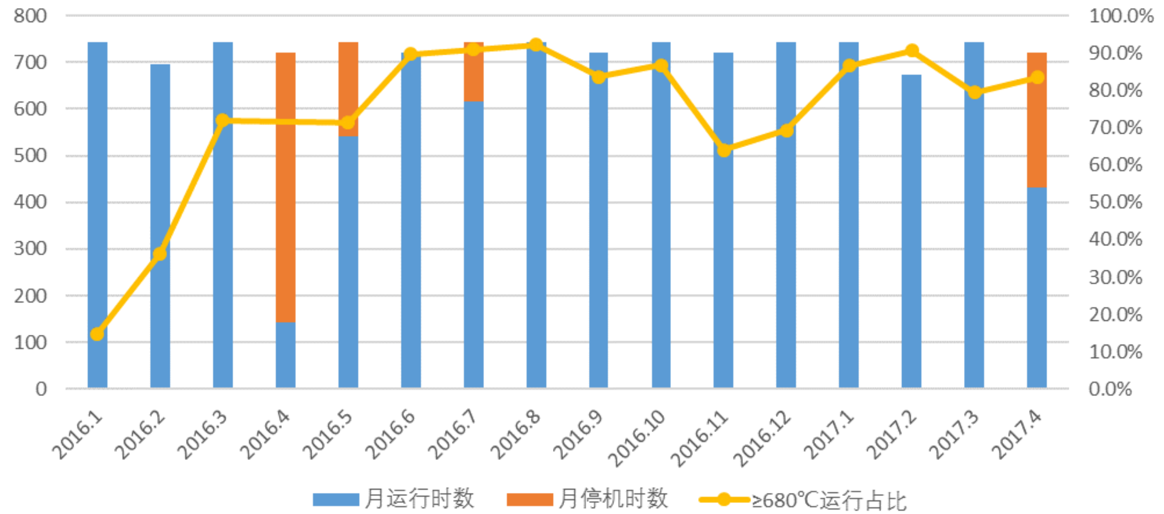
启动及168试验 Initiation and 168 Hours Experiment

- 2015年12月28日21:20，宿主机组开始点火启动，至12月30日14:04，主蒸汽温度成功达到700℃，主蒸汽压力24.03MPa
- Host unit started on 2015/12/28 21:20. Main steam temperature reached 700℃ by 12/30 14:04.
- 2016年1月17日~1月24日，完成了168小时试运试验（其中72小时满负荷），试验平台700℃运行。168小时试运期间，所有相关设备运行稳定，各项参数显示正常，各项指标符合设计要求，实现了对关键部件的验证
- 168 hours test experiment run through 2016/1/17~2016/1/24 with 72 hours full load, the test facility run at temperature of 700℃. During the test run, all related devices remained stable, every parameter stayed normal, each design target was met, related nickel components were validated

运行试验研究Running Experiment Study

整体运行情况 Overall Running Status

- 截止2017年4月18日A修，700℃平台累计运行时间10523小时
- Facility running for 10523 hours until maintenance on 2017/4/18
- 2016年度蒸汽温度≥680℃占比66.6%，2017年一季度占比85%
- Steam temperature above 680℃ was 66.6% in 2016, 85% in first quarter of 2017
- 目前最长连续运行 By now longest running time continuously is 267 days
- 计划验证试验为期4万小时 Entire test period is planed to be 40,000 hours



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后续验证试验工作 Following work

- 保证平台长期稳定可靠运行 Ensure long and stable run
- 运行监测和数据分析 Running monitor and data analysis
- 每次机组停机时，应对受热面管子、集箱、管道、阀门等进行检验；当试验部件因检修需要或达到一定时间需要切割取样时，应对各种样品进行详细的试验分析工作；平台的热力性能试验分析 Each time unit shut down, check components; when components need to be cut or sampled, samples should be analyzed thoroughly by experiment; thermal performance analyze
- 缺陷与故障分析 Shortcoming and error analysis
- 对于满足要求的新研发高温合金材料（国产材料），可在试验平台上进行实炉验证试验 Newly developed high temperature alloy material (mainly domestic) that meets requirement of this project can be applied and tested on the test facility.

成为我国电站高温材料验证试验平台 To become the test facility for China's power plant high temperature material for different temperature

主要内容 Table of Content

结论 Conclusion

- **700℃超超临界燃煤机组是我国高效清洁燃煤发电技术的必然选择**
- **700℃ Ultra-supercritical Coal-fired unit is the inevitable choice for high efficiency, clean Coal-fired power generation**
- **国外尤其是欧洲国家针对700℃机组进行了较为深入的研究，由于材料问题，示范机组的建设计划被延后。国内相关研究近年积极进行中**
- **Foreign countries, esp. European has done extensive research on 700℃ technique, but delayed. Domestic research is active recent years.**
- **建立一座700℃示范机组前，有必要先建设关键部件验证试验平台**
- **Key component test facility is essential before 700℃ demonstration**
  - ✓自主设计建设了我国首个700℃发电机组关键部件验证试验平台
  - ✓Designed and built the first 700℃ key component test facility in China

结论 Conclusion

✓在平台上对国内外10个不同牌号的新型耐热材料开展了验证工作

✓Tested and validated 10 different new high temperature material

✓开发了耐热材料关键部件的制造、加工、焊接和现场安装工艺

✓Developed the manufacture, process, weld and install tech of key components with high temperature material

✓已经投运1年多时间，运行情况良好，后续将完成相关试验研究

✓Been run for over a year with good operation situation, related research and experiment are in due

- 在验证平台建设验证试验成功的基础上，我国将适时开展700℃示范机组建设，700℃技术在我国有光明的发展前景
- **Based on the success of the component test facility, 700℃ demonstration will begin at proper time. This tech has great potential in China.**

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CTF700

700℃关键部件验证试验平台

700℃ Component Test Facility

Thanks!