Pollutant Control in China's Coal-fired Power Generation Industry

燃煤电厂污染物的控制

电力规划设计总院

Electric Power Planning & Engineering Institute

2015 年 1 月 河北省石家庄市

Jan, 2015

Shijiazhuang, Hebei, China

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Background introduction

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Relevant environment protection policies & rules

3. 燃煤电厂污染物的控制技术
Pollutant emission control technologies for coal-fired power plants

4. 超净排放典型工程
Typical Super low emission projects

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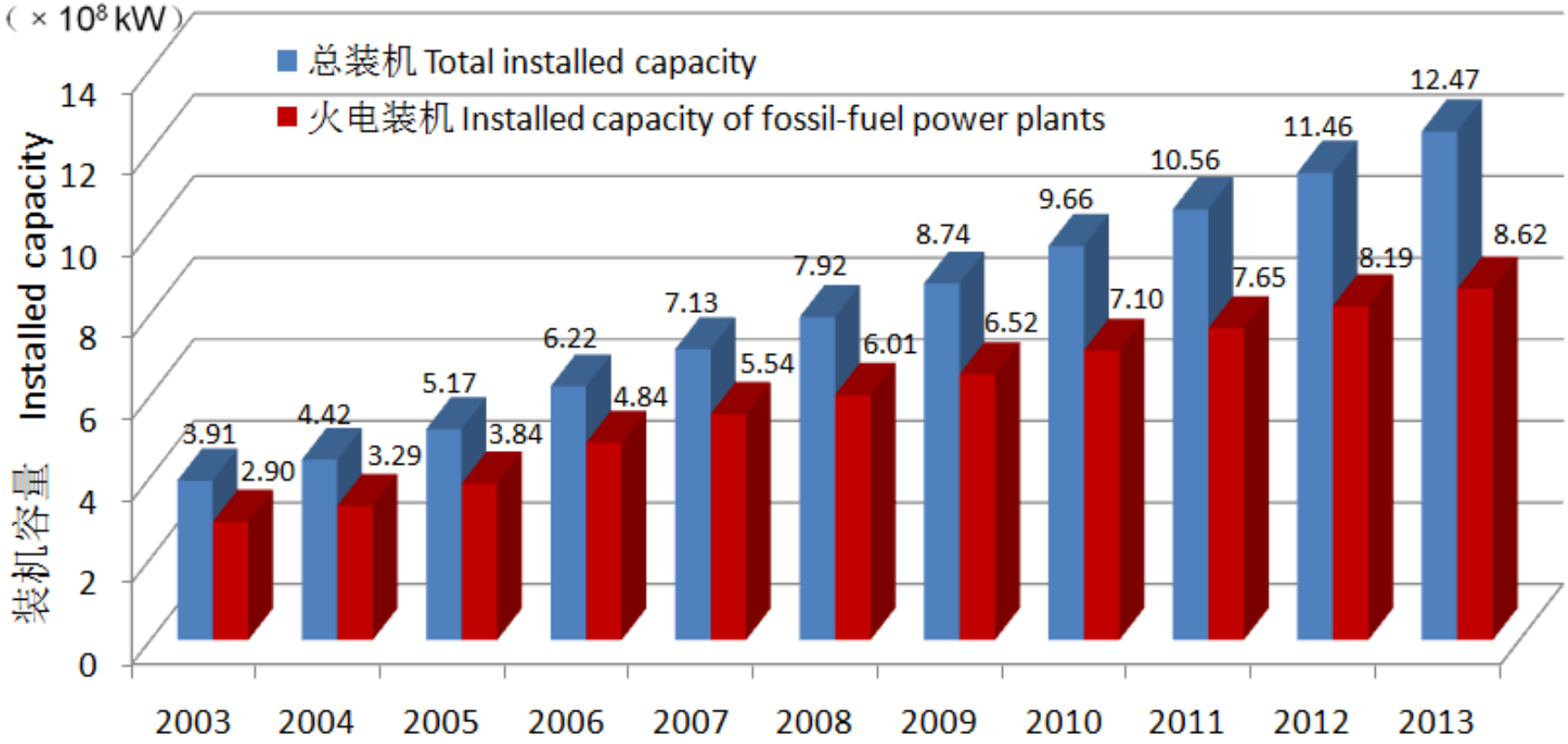
中国电力装机容量 China's installed power generation capacity



2003-2013年中国电力装机容量的变化

Trend of China's total installed power generation capacity, 2003-2013

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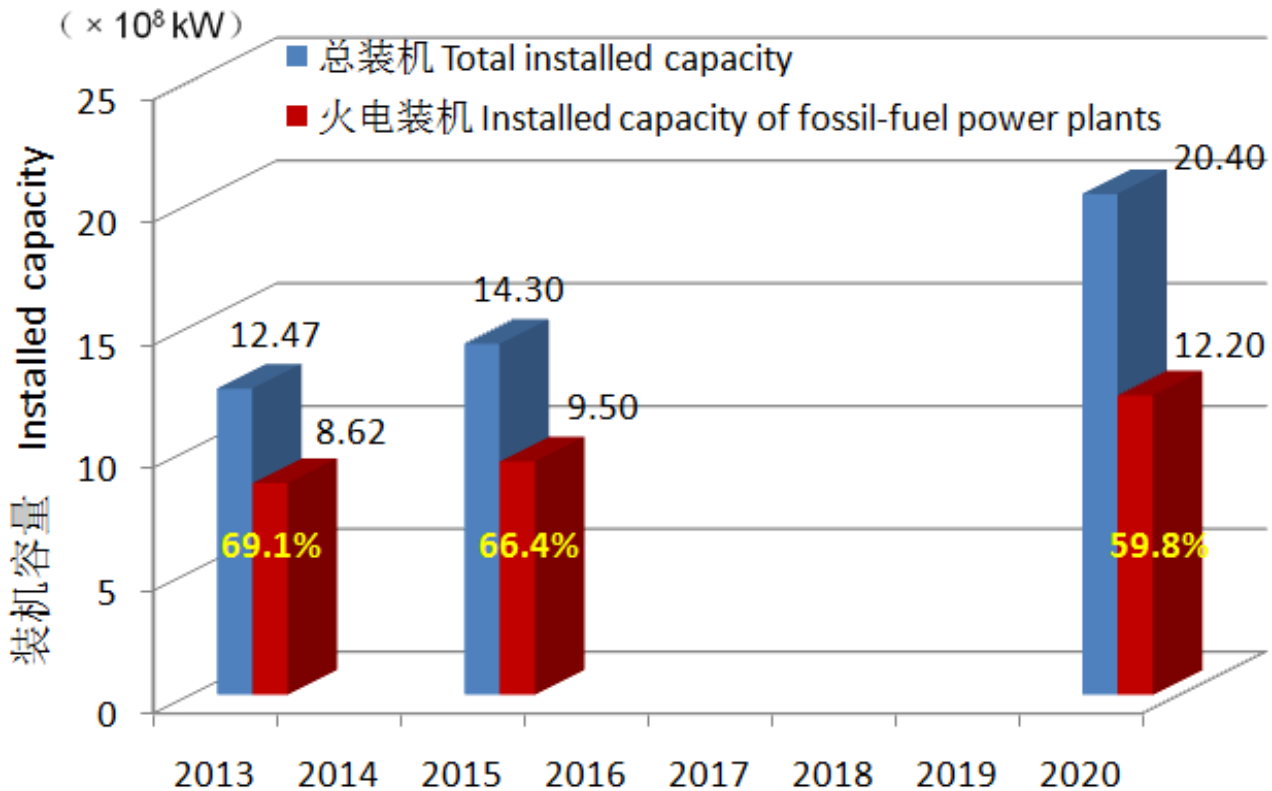

中国发电装机容量的预测

Forecast of China's installed power generation capacity

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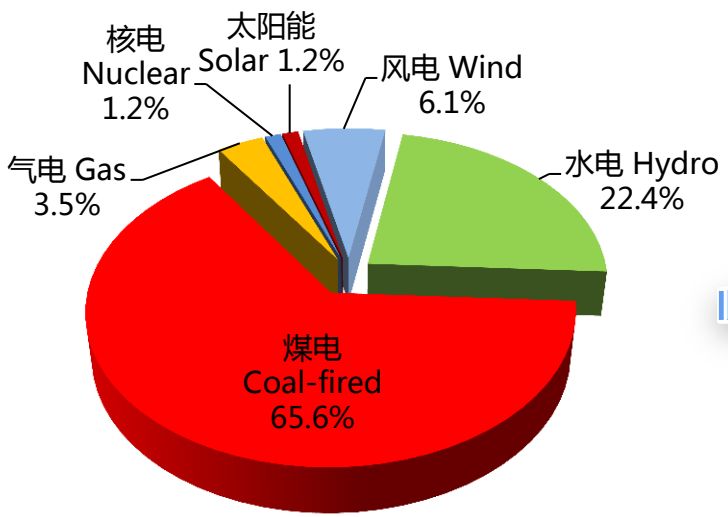
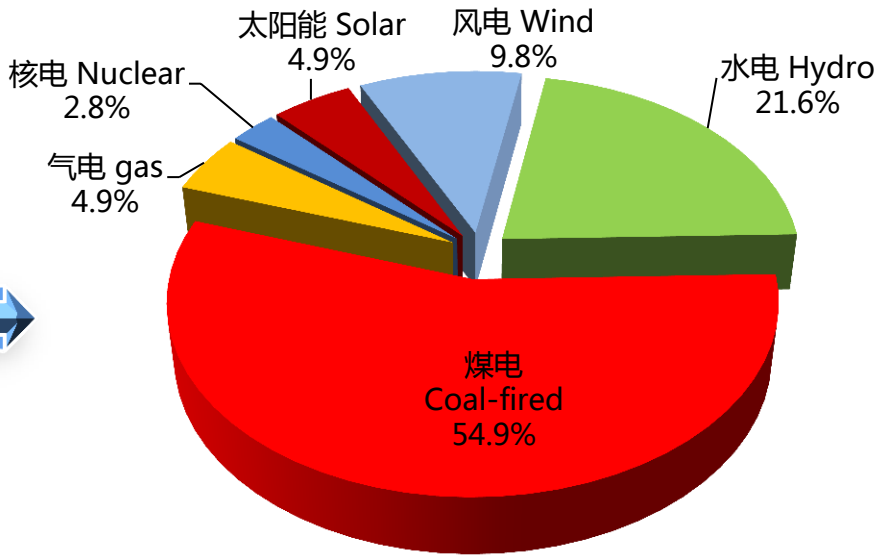
中国电力装机结构 China's installed power generation structure

- 中国一次能源的结构特征决定了火电在中国仍占很大比重。
  The energy structure determines fossil-fuel power plants still plays the dominant role in China's power generation industry.



2013年全国装机构成，总装机124738万千瓦
Installed power structure at 2013
total capacity 1247GW



预计2020年全国装机构成，总装机204000万千瓦
Predicted Installed power structure at 2020
total capacity 2040GW

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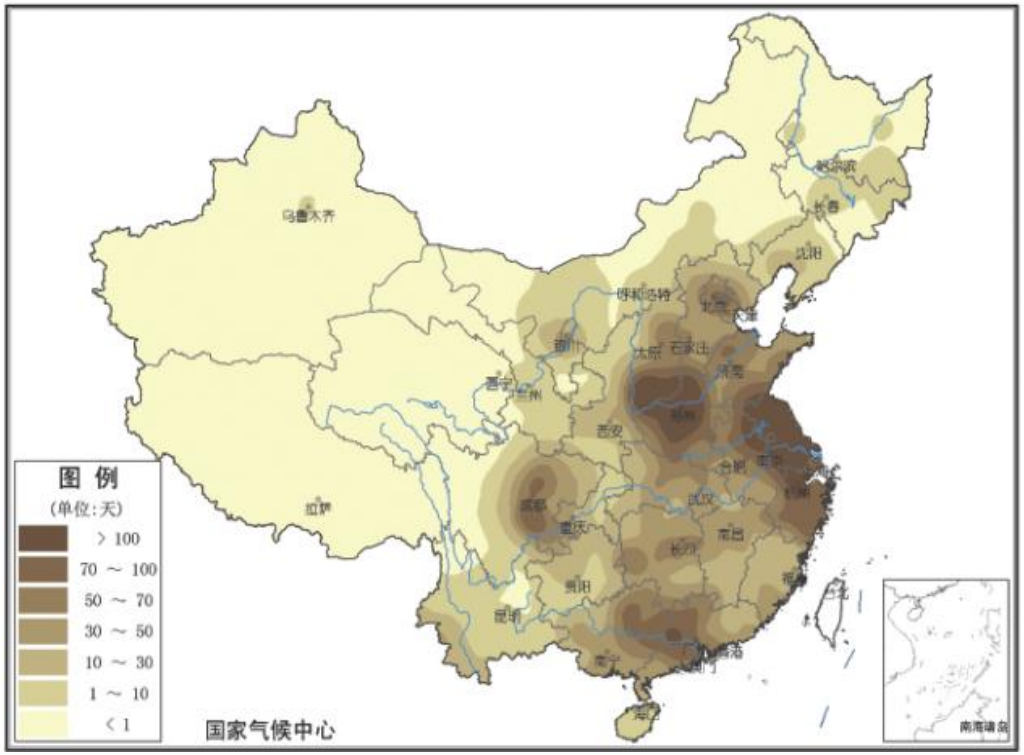
大气灰霾成为重大民生问题 Air pollution becomes a severe problem

- 2013年，我国灰霾面积最高达143万平方公里，波及15%国土面积；全国平均灰霾日数35.9天，部分地区超过100天。

  In Year 2013, the total area influenced by haze was up to 1,430,000 km^2, occupied 15% of China. The average haze day was 35.9, some regions even exceeded 100.



2013年全国霾日数分布示意图
Haze day number distribution around China, 2013

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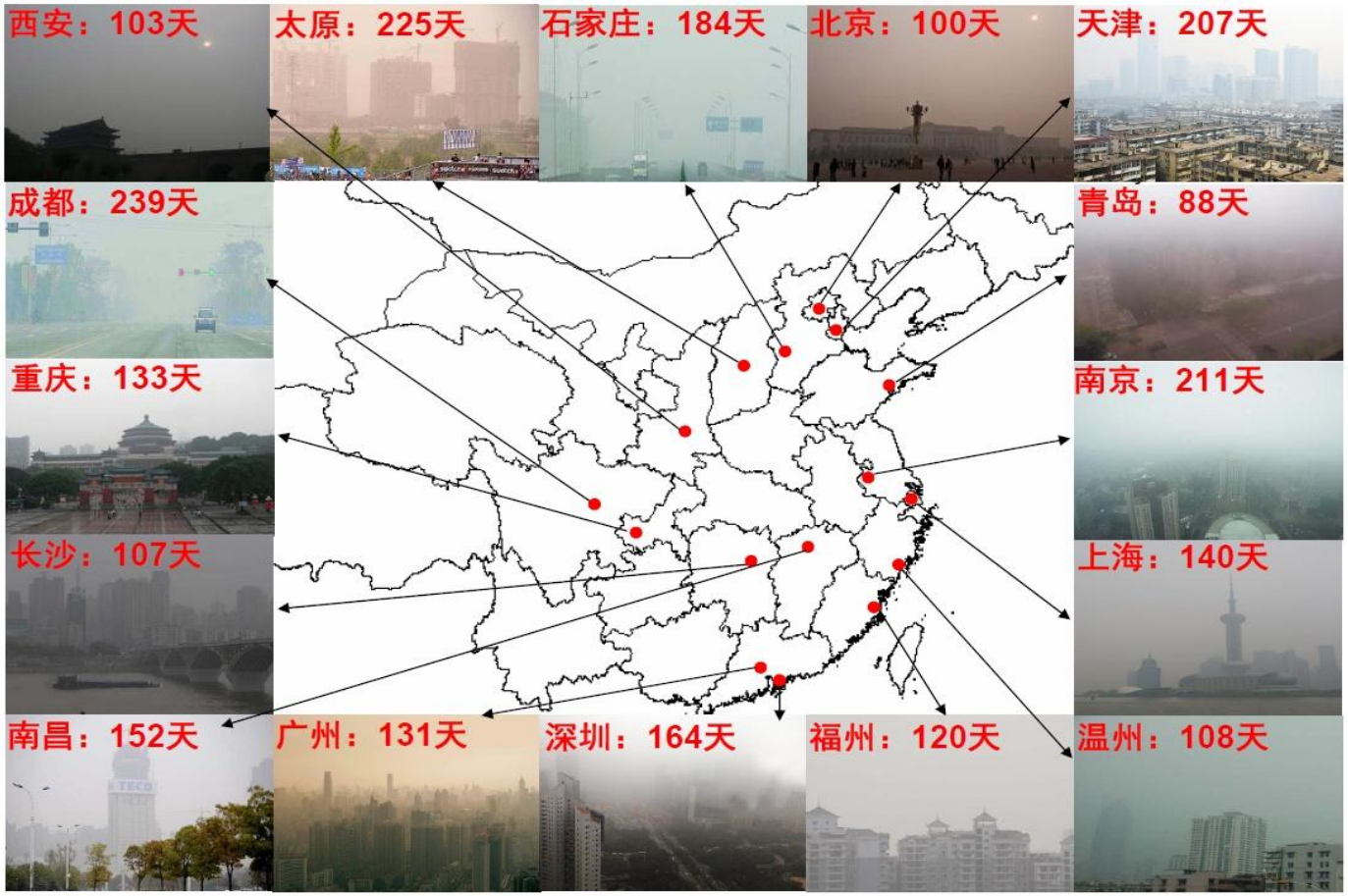
大气灰霾成为重大民生问题 Air pollution becomes a severe problem



2013年全国主要城市霾日数统计
Total number of haze day in major cities, 2013

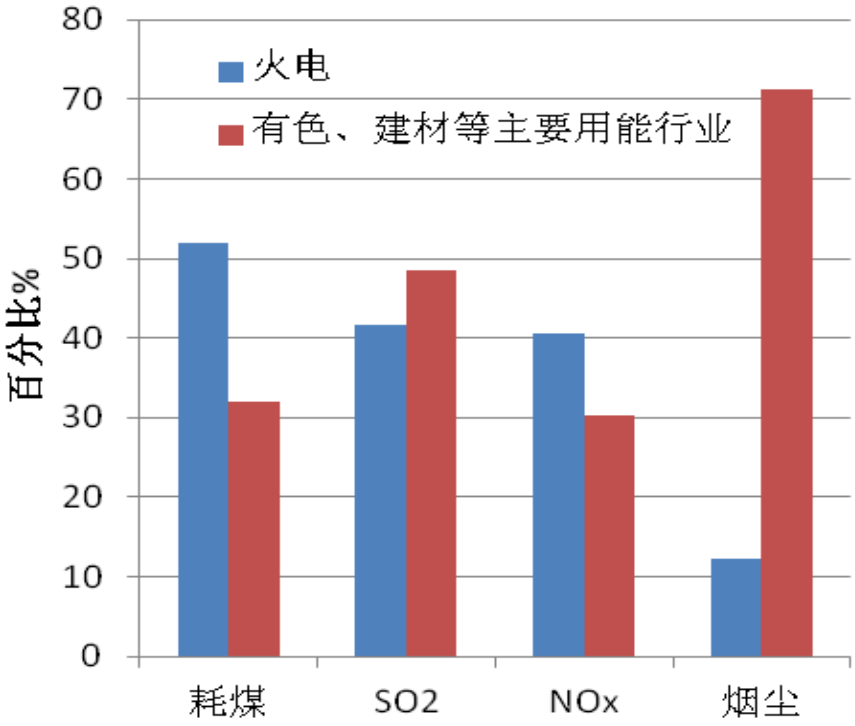
大气灰霾成为重大民生问题 Air pollution becomes a severe problem

- 研究表明，我国大气污染主要为煤烟型污染和机动车尾气污染的大气复合污染，燃煤污染为主；

  Research shows that air pollution in China is mainly the combination of coal gas and automobile emission, primarily coal gas.

- 2012年我国火电行业排放二氧化硫883万吨、氮氧化物948万吨、烟尘151万吨，分别占全国总排放量的41.7%、40.6%、12.2%。

  In 2012, the total emission from coal-fired industry is SO2 883×10^4t, NOx 948×10^4t, dust 151×10^4t. That is 41.7%, 40.6%, 12.2% of the total pollutant emission, respectively.



2012年火电和其它主要用能行业耗煤和污染物排放占全国比例

Percentage of emission from coal-fired industry and other industries, 2012

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火电环保标准 Development of “Pollutant emission standard”

- 《火电厂大气污染物排放标准》GB13223-1996，该标准自1997年1月1日起实施。
  The “Pollutant emission standard” (GB13223-1996) was executed on Jan 1st, 1997.
- 《火电厂大气污染物排放标准》GB13223-2003，该标准自2004年1月1日起实施，废止GB13223-1996标准。
  The “Pollutant emission standard” (GB13223-2003) was executed on Jan 1st, 2004.
- 《火电厂大气污染物排放标准》GB13223-2011，该标准自2012年1月1日起实施，废止GB13223-2003标准。
  The “Pollutant emission standard” (GB13223-2011) was executed on Jan 1st, 2012.

新建、扩建燃煤电厂	烟尘 / Dust mg/Nm^3	二氧化硫 / SO_2 mg/Nm^3	氮氧化物 / NOx mg/Nm^3
GB13223-1996	200～600	1200～2100	650～1000
GB13223-2003	50～200	400～1200	450～1100
GB13223-2011	20～30	50～200	100～200

火电环保排放标准演变
Development of emission standard in coal-fired industry

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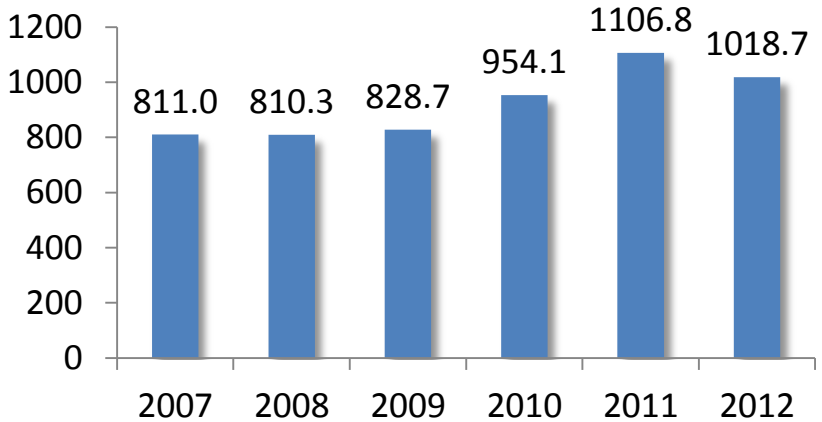
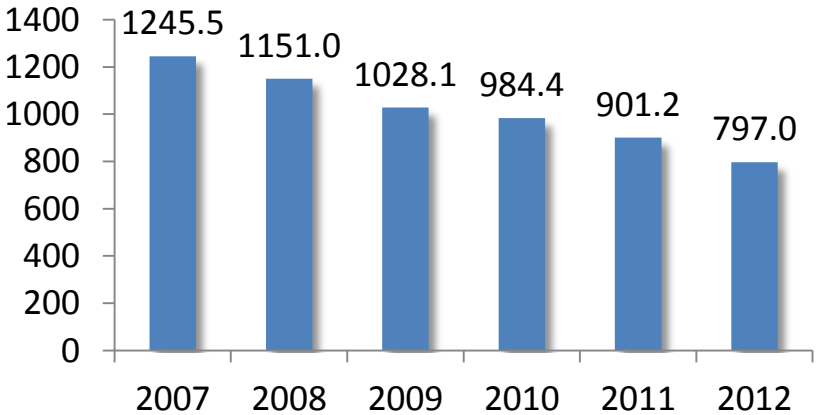
火电环保标准实施效果 Effect of “Pollutant emission standard”

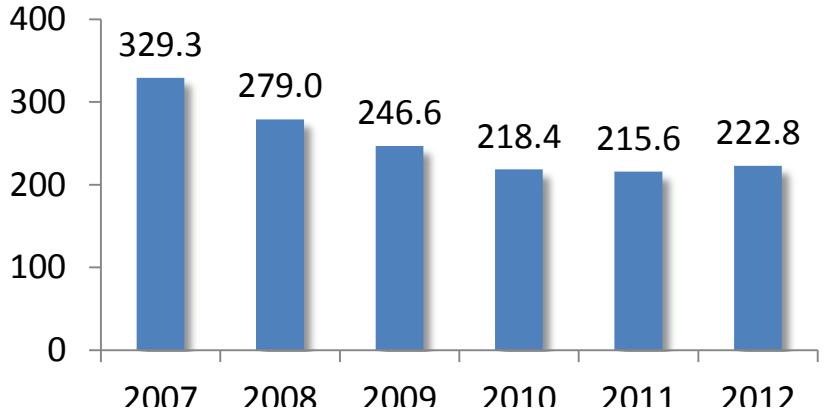
- 随着火电排放标准日渐严格，中国积极推进火电机组技术优化和升级，污染物排放在一定程度上得到控制。
  China has been promoting the optimizing and upgrading of fossil fuel power plants, the pollutant emissions have been controlled effectively.



电力行业NOx排放量/万吨 （2011年装设脱硝）
NOx emission in power generation industry/10^4t
（equipped with de-NOx since 2011）



电力行业SO_2排放量/万吨 （2007年装设脱硫）
SO_2 emission in power generation industry/10^4t
（equipped with de-SOx since 2007）



电力行业烟尘排放量/万吨
Dust emission in power generation industry/10^4t

火电环保标准比较 Comparison of “Pollutant emission standard”

- 2011年7月29日，中国发布了《火电厂大气污染物排放标准》（GB13223-2011），此标准实施后，燃煤电厂的污染物排放将大幅降低 。
  On July 29 2011, the “Pollutant emission standard” (GB13223-2011) has been published, and as a result, the pollutant emission decrease tremendously.

国 家 / Country	烟 尘 / Dust mg/Nm^3	二氧化硫 / SO_2 mg/Nm^3	氮氧化物 / NOx mg/Nm^3
美 国 / USA	20	184	135
日 本 / Japan	50-100	200	200
欧 盟 / EU	30	200	200
澳大利亚 / Australia	100	200	460
加拿大 / Canada	130	740	460
新西兰 / New Zealand	125	350	410
中 国（非重点地区） China’s normal region	30	100-400	100-200
中 国（重点地区） China’s crucial region	20	50	100

重点地区排放标准 Crucial areas' emission control

- 重点控制区共47个城市，具体包括：京津冀地区、长三角地区、珠三角地区、沈阳市、济南市、青岛市、淄博市、潍坊市、日照市、武汉市、长沙市、重庆市主城区、成都市、福州市、三明市、太原市、西安市、咸阳市、兰州市、银川市、乌鲁木齐市。

  Crucial areas includes 47 cities, that is: Beijing-Tianjin-Hebei region, Changjiang triangle region, Zhujiang triangle region, Shenyang, Jinan, Qingdao, Zibo, Weifang, Rizhao, Wuhan, Changsha, main city area of Chongqin, Chengdu, Fuzhou, Sanming, Taiyuan, Xi'an, Xianyang, Lanzhou, Yinchuan, Urumuqi.

污染物 Pollutant	适用条件 Situation	限值 mg/Nm^3 Emission limit
烟尘 / Dust	全 部 / all	20
二氧化硫 / SO2	全 部 / all	50
氮氧化物 / NOx	全 部 / all	100
汞 / Hg	全 部 / all	0.03

重点区域排放标准（GB13223-2011）
Emission criteria in crucial region (GB13223-2011)

火电排放相关政策 Relevant policies for coal-fired industry

国务院“节能减排十二五规划”，2012年8月6日

- 推进电力行业脱硫脱硝及大气中细颗粒污染物（PM2.5）治理；加大工业烟粉尘污染防治力度，对火电、钢铁、水泥等高排放行业以及燃煤工业锅炉实施高效除尘改造，到2015年火电行业二氧化硫和氮氧化物排放量分别达到800万吨和750万吨，比2010年降低16%和29%。
- Promote the treatment of de-SOx and de-NOx and PM2.5; dust removal modification to the coal-fired, iron, cement ; until 2015, the SO2 and NOx emission in coal-fired industry reduce 800×10^4t and 750×10^4t, 15% and 29% compared with 2010.

国务院“大气污染防治十条措施”，2013年6月14日

- 加快重点行业脱硫脱硝除尘改造，大力推行清洁生产，重点行业主要大气污染物排放强度到2017年底下降30%以上。
- Speed up the de-SOx, de-NOx and dust removal modification, the pollutant emission in major industries reduce 30% by the end of 2017.

煤电节能减排升级与改造行动计划，2014年9月12日

火电排放相关政策 Relevant policies for coal-fired industry

煤电节能减排升级与改造行动计划，2014年9月12日

- 严控大气污染物排放。东部地区（辽宁、北京、天津、河北、山东、上海、江苏、浙江、福建、广东、海南等11省市）新建燃煤发电机组基本达到燃气轮机组排放限值（烟尘、二氧化硫、氮氧化物排放浓度分别不高于10、35、50毫克/立方米），中部地区（黑龙江、吉林、山西、安徽、湖北、湖南、河南、江西等8省）新建机组原则上接近或达到燃气轮机组排放限值，鼓励西部地区新建机组接近或达到燃气轮机组排放限值。支持同步开展大气污染物联合协同脱除，减少三氧化硫、汞、砷等污染物排放。
- Stricty control emission. Newly built power plants in East China (Liaoning, Beijing, Tianjin, Hebei, Shandong, Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong, Hainan) emission as gas turbine (dust<5mg/Nm3, SO2<35mg/Nm3, NOx<50mg/Nm3) ; Newly built power plants in Middle China (Heilongjiang, Jilin, Shanxi, Anhui, Hubei, Hunan, Henan, Jiangxi) emission near gas turbine; Newly built power plants in western China are encouraged to gas turbine emission.
- 推进环保设施改造。重点推进现役燃煤发电机组大气污染物达标排放环保改造。稳步推进东部地区现役30万千瓦及以上公用燃煤发电机组和有条件的30万千瓦以下公用燃煤发电机组实施大气污染物排放浓度基本达到燃气轮机组排放限值的环保改造，2014年启动800万千瓦机组改造示范项目，2020年前力争完成改造机组容量1.5亿千瓦以上。鼓励其他地区现役燃煤发电机组实施大气污染物排放浓度达到或接近燃气轮机组排放限值的环保改造。
- Promote the environmental protection facilities modification. The power plants in eastern China with 300MW or more capacity, will modified to gas turbine emission; other regions are encouraged to gas turbine emission.

山东省相关政策 Emission standard in Shandong Province

- 山东
- 河北

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污染物减排技术 Pollutant emission control technologies

除尘技术 Dust Removal

- 电除尘器 ESP
- 布袋除尘器 Baghouse
- 电袋除尘器 ESP-baghouse
- 低低温电除尘 Low low temperature ESP
- 湿式电除尘 Wet ESP
- 高效除尘吸收塔 High efficiency absorption tower

脱硫技术 Desulfuration

- 石灰石-石膏湿法 Limestone-gypsum
- 半干法 Half-wet
- 炉内脱硫 De-SOx inside furnace
- 海水脱硫 Sea water de-SOx
- 氨法脱硫 Ammonia de-SOx

脱硝技术 Denitration

- 低氮燃烧技术 Low-NOx combustion
- 选择性催化还原 SCR
- 选择性非催化还原 SNCR

除尘技术—主要技术手段 Dust removal-technologies

- 电除尘器：多数煤种对电除尘器适应性比较好，除尘效率低于**99.8%**。
  electrostatic precipitator: suitable for most coal sources. If required dust removal efficiency is not larger than 99.8%.

- 电除尘器加高频电源、旋转电极：除尘效率介于**99.8%**和**99.85%**之间。
  electrostatic precipitator with high-frequency electric source, rotation electrode: 99.8% < efficiency < 99.85%.

- 低低温电除尘器、湿式电除尘器、布袋除尘器、电袋除尘器：除尘效率高于**99.85%** 。
  Low low temperature electrostatic precipitator, wet electrostatic precipitator, baghouse filter, Electrostatic Fabric filter: efficiency > 99.85%.

除尘技术—主要技术手段 Dust removal-technologies

布袋除尘器
Baghouse filter

- 袋式除尘器（包括布袋除尘器以及电袋复合除尘器）对粉尘特性不敏感，不受煤种、飞灰成分、浓度和比电阻的影响。
  Baghouse filter is not sensible to dust characteristic, and not influecenced by coal, ash source and specific resistance.

采用布袋除尘器的电厂 Power plants using baghouse filter		机组容量 Unit capacity
内蒙呼市热电厂	Huhehot city thermal unit	200 MW
石门电厂	Shimen unit	300 MW
大唐华银株洲电厂	Datang Zhuzhou unit	300 MW
湘潭电厂	Xiangtan units	600 MW
新密电厂	Xinmi power plant	1000 MW

除尘技术—主要技术手段 Dust removal-technologies

低温电除尘器
Low temperature electrostatic precipitator

- 漕泾电厂1000MW机组：除尘器进口加装低温省煤器后，烟温从123℃降低到约105℃，电除尘器效率从99.81%提高到99.87%，出口排放浓度从21.57mg/Nm^{3}降低到14.29mg/Nm^3。
  Caojing 1000MW power plant: With the low temperature economizer at the inlet of dust filter, flue gas temperature drops from 123°C to 105°C, dust filter efficiency rises from 99.81% to 99.87%, emission from outlet drops from 21.57mg/Nm^3 to 14.29mg/Nm^3.

低低温电除尘器
Low low temperature electrostatic precipitator

- 低低温静电除尘器的合同业绩（华能浙江长兴电厂）。
  The contract for Low low temperature electrostatic precipitator: Huaneng Zhejiang Changxing power plant.

湿式电除尘器
wet electrostatic precipitator

- 国华舟山电厂4号机组（350MW），已于2014年6月25日投运。
  Guohua Zhoushan No.4 unit (350MW), operating since June 25th 2014.
- 浙能六横电厂1号机组（1000MW），已于2014年7月10日投运。
  Zhenneng Liuheng No.1 unit (1000MW), operating since July 10th 2014.

除尘技术—影响因素 Dust removal-influential factors

煤质影响 Coal quality

- 电除尘：煤质的影响主要体现在燃煤性质（成分、挥发分、发热量、灰熔融性等）、飞灰性质（成分、粒径、密度、比电阻、粘附性等）、烟气成分等。 Promote the treatment of de-SOx and de-NOx and PM2.5; dust removal modification to the coal-fired, iron, cement ; until 2015, the SO2 and NOx emission in coal-fired industry reduce 800×10^4t and 750×10^4t, 15% and 29% compared with 2010.
- 灰硫比对低低温电除尘器有重要影响。当低低温电除尘器采用含硫量为2. 5%的燃煤时，灰硫比在50~100可避免腐蚀，当采用含硫量更高的燃煤时，为避免腐蚀，灰硫比应大于200。 Ash-Sulf ratio is crucial to low low temperature ESP. when using low low temperature ESP with coal contains 2.5% sulf, erosion can be avoid when ash-sulf ratio between 50~100; when sulf larger than 2.5%, ash-sulf ratio must larger than 200 to avoid erosion.
- 烟气温度对飞灰比电阻具有较大影响，烟温从150℃降到100℃左右，比电阻降幅一般可达到一个数量级以上。 The temperature of ash is crucial to specific resistance. When flue gas temperature drop from 150℃ to 100℃, specific resistance would reduce an order of magnitude.

炉型的影响 Type of furnace

脱硫系统的影响 Desulfuration system

除尘技术—影响因素 Dust removal-influential factors

煤质影响 Coal quality

炉型的影响 Type of furnace

- 煤粉锅炉：煤粉锅炉采用中、低灰煤，个别用富灰煤，基本符合使用电除尘器的要求，目前国内电厂绝大部分都采用电除尘器+湿法脱硫吸收塔除尘工艺。 ESP is commonly used in coal powder furnace, and ESP + wet de-SOx absorption tower is mostly used in China.
- 循环流化床锅炉：由于煤质的较差，以及循环流化床锅炉较多采用炉内脱硫以及半干法脱硫，因此袋式除尘器在循环流化床机组中使用相对较多。 Due to the low quality coal used in CFB boiler, and the de-SOx technologies are inside furnace or half wet, baghouse filters are widely used in CFB boiler.

脱硫系统的影响 Desulfuration system

- 脱硫吸收塔的综合除尘效果是重要影响因素。对于采用常规电除尘器或袋式除尘器的机组，吸收塔除尘效率约50%。高效除尘吸收塔结合低低温电除尘器，更具经济性和先进性。 The dust removal effect in absorption tower when using ESP or baghouse is about 50%. High efficiency absorption tower along with low low temperature ESP is more economical and advanced.

除尘技术—技术路线选择 Dust removal-technology routine

（低低温）电除尘器（采用提效措施）＋吸收塔除尘＋湿式除尘器

- 电除尘器配合各类提效措施，如移动电极技术、分室振打技术、高频电源等，使电除尘器出口浓度不大于20 mg/Nm^3。考虑吸收塔的整体除尘效果后，再配置70%左右除尘效率的湿式除尘器，烟尘排放可达到5mg/Nm^3。如：浙能六横电厂。 ESP combined with moveable electric paddle, separate room vibration, high-frequency electric source, can reduce dust at the exit of ESP to 20mg. Considering the dust removal effect in absorption tower, and with wet ESP at 70% efficiency, the dust emission can be no large than 5mg.

低低温电除尘器＋高效除尘吸收塔

- 采用低低温电除尘器，使电除尘器出口浓度不大于15~20 mg/Nm^3，采用高效除尘吸收塔后，烟尘排放可达到5mg/Nm^3。如：华能长兴电厂。 Apply low low temperature ESP to reduce the exit dust to 15~20mg, and use high efficiency absorption tower to achieve dust emission at 5mg.

袋式除尘器

除尘技术—技术路线选择 Dust removal-technology routine

（低低温）电除尘器（采用提效措施）＋吸收塔除尘＋湿式除尘器

低低温电除尘器＋高效除尘吸收塔

袋式除尘器

- 布袋除尘器占地小，对粉尘特性不敏感，不受煤种、飞灰成分、浓度和比电阻的影响，除尘效率高，排放稳定；但缺点也较明显：压力损失大，对烟气的温度和湿度较为敏感，滤袋寿命较短，更换费用较高。废袋在国内尚无完善的处理措施。 Baghouse filters are small, and insensitive to ash character, nor influenced by the type of coal, ash, or specific resistance. Baghouse has high efficiency and stable emission. Its deflection is obvious for the large pressure loss and sensitive to temperature and humidity of flue gas. The life time of bag is short and the price is high.
- 袋式除尘器一般可以保证出口排放浓度在20mg/Nm^{3}以下，最好的可以达到5mg/Nm^3（进口滤袋）。若采用湿法脱硫，袋式除尘器+吸收塔是否可以达到燃机排放，需进一步论证。Baghouse filter can guarantee the exit dust lower than 20mg, 5mg at best (inlet filter bag). If wet desufuration is used, whether baghouse + absorption technology can reach gas turbine emission level is not for sure.

脱硫技术—主要技术手段 Desulfuration-technologies

- 石灰石-石膏湿法脱硫，单塔脱硫效率一般可达到97.5%
  Limestone-gypsum wet flue gas desulphurization (single tower efficiency is 97.5%).
- 高效的湿法脱硫技术：单塔双循环、双塔双循环、吸收塔两级串联、带双托盘的吸收塔，脱硫设计效率可超过97.5%
  High efficiency wet desulphurization methods: single tower dual cycle, dual tower dual cycle, absorbing tower connecting in series, double pallet absorbing tower (efficiency > 97.5%).

单塔双循环
Single tower dual cycles

- 已投运电厂：广州恒运电厂2×300MW机组，国电肇庆2×350MW机组等
  Power plants in operation: Guangzhou Hengyun 2×300MW units, Guodian Zhaoqing 2×350MW units.

序 号 No.	处理前SO_2浓度 SO_2 before de-SO_2	处理后SO_2浓度 SO_2 after de-SO_2	单 位 Unit
1	1689	11	mg/Nm^3
2	1646	9	mg/Nm^3
3	1699	13	mg/Nm^3
4	1651	10	mg/Nm^3
平均值	1671	11	mg/Nm^3

恒运电厂单塔双循环脱硫性能测试报告
Test report of desulfuration system of Guanzhou Hengyun power plant

脱硫技术—主要技术手段 Desulfuration-technologies

双塔双循环
Dual tower dual cycle

- 主要解决现有电厂使用高硫煤导致的原脱硫系统出力不足问题
  Solve the problem that the under-capacity of the original system when encounter high sulfur content coal.
- 充分利用已有脱硫相关设备，改造原吸收塔，又避免了拆塔重建的最不利局面
  Use the existed desulfuration devices, modify the original tower, avoid the cost for reconstruction.
- 在不改变脱硫剂的情况下，显著提高了脱硫效率，大大减少改造工期和主机停运时间，降低了整个技改工程造价
  Without changing desulfurizer, dual tower dual cycle system improves desulfuration efficiency, decrease modification cost of time and capital.

吸收塔两级串联
absorption towers in series

- 两个吸收塔串联，以提高脱硫效率
  Two absorption towers in series to increase desulfuration efficiency.

带双托盘的吸收塔
double pallet absorbing tower

- 吸收塔采用带托盘的喷淋塔，提高了塔内脱硫效率
  With pallet on the absorption tower, the desulfuration efficiency inside the tower can be improved.
- 与同类湿法脱硫技术相比约可降低40%以上的浆液循环量，从而大副降低物耗及能耗
  40% more of the circulated seriflux can be saved compared to convential desulfuration technologies, therefore decrease mass and energy consumption.

脱硫技术—影响因素 Desulfuration-influential factors

煤质影响 Coal quality

- 煤的含硫量S是烟气中SO_2浓度的主要影响因素。含硫量S越大，烟气中SO_2浓度的亦将越高，需要脱硫技术的效率更高。 The sulf percentage in coal is the main factor of SO2 in flue gas.
- 根据环保总局《燃煤二氧化硫排放污染防治技术政策》的规定，燃煤开采的含硫量一般不超过3%。 According to the <SO2 emission control policy for coal>, the sulf percentage is usually not larger than 3%.

炉型的影响 Type of furnace

- 煤粉锅炉：国内煤粉锅炉大多采用石灰石－石膏湿法脱硫。 Coal powder furnace: Limestone-gypsum wet flue gas desulphurization is commonly used.
- 循环流化床锅炉：国内循环流化床锅炉目前多采用炉内喷钙脱硫，但当煤种含硫量较高时，大型机组增设石灰石－石膏湿法脱硫，小型机组增设半干法脱硫，结合炉内喷钙两级脱硫实现超低排放。 CFB boiler: usually use calcium injection desulfuration technique. When the sulf percentage in coal is high, Limestone-gypsum can be applied to large units, half wet can be applied to small units, combined with the inside furnace calcium injection to realize super low emission.

脱硫技术—技术路线选择 Desulfuration-technology routine

优先选用石灰石－石膏湿法脱硫

- 石灰石—石膏湿法脱硫是目前世界上技术最成熟、应用最广、运行最可靠的方法，适用于任何含硫量的煤种的烟气脱硫，脱硫效率可达到99%以上。 Limestone-gypsum can be applied to coal with any percentage of sulf, its efficiency can be more than 99%.

循环流化床优先选用炉内喷钙脱硫

- 循环流化床锅炉燃烧方式特殊，非常适合使用炉内喷钙脱硫技术。炉内喷钙脱硫装置成本较低，一般优先选择炉内喷钙脱硫工艺作为SO_2排放控制的手段。 CFB boiler is suitable for calcium injection method. calcium injection method is low cost.

半干法脱硫仅用于小型机组

- 半干法脱硫目前在国内多用于小型机组，只有极个别1000t级机组使用了半干法脱硫技术。 Half wet desulfuration is used in small units.

各脱硫技术的脱硫效率限定

- 石灰石－石膏湿法脱硫法（单塔）效率极限：99%；石灰石－石膏湿法脱硫法（双塔）效率极限：99. 75%；炉内喷钙脱硫法效率极限：90%；半干法脱硫法效率极限：95%。 The Limestone-gypsum (single tower) efficiency limit: 99%; The Limestone-gypsum (dual tower) efficiency limit: 99.75%; calcium injection efficiency limit: 90%; half wet efficiency limit: 95%.

脱硝技术—主要技术手段 Denitration-technologies

- 炉内低NOx燃烧技术：约90%的机组建设或进行了低NOx燃烧改造。
  Low NOx burning technology inside furnace: about 90% units have constructed or done the low NOx burning modification.

- 在SCR工艺与SNCR工艺之间进行比选，考虑到《火电厂大气污染物排放标准》GB13223-2011要求新建燃煤电厂氮氧化物排放浓度限值100mg/Nm^3，一般采用加炉后SCR脱硝技术(占脱硝装机的99%以上)。
  Comparing the common used SCR and SNCR technologies, and considering the requirement from “Power plants emission criteria” (GB13223-2011), NOx emission should not exceed 100mg/Nm^3, SCR is widely applied, occupies more than 99% of the total capacity.

- 脱硝效率
  Efficiency for denitration
  - 效率40～50%，配置1层催化剂，预留2层，即1+2布置方式
    Efficiency between 40% to 50%, install 1 layer of catalyzer, 2 layers for reservation.
  - 效率50～80%，配置2层催化剂，预留1层，即2+1布置方式
    Efficiency between 50% to 80%, install 2 layers of catalyzer, 1 layer for reservation.
  - 效率大于80%，采用配置3层运行催化剂层，即3+1布置方式
    Efficiency > 80%, install 3 layers of catalyzer, 1 layer for reservation.

脱硝技术—影响因素 Denitration-influential factors

煤中氮元素的影响 Coal quality

- 当燃烧温度低于1000℃时，热力型NOx的生成量很小；煤粉炉（包括“W”型火焰炉）燃用无烟煤或贫煤时，由于燃烧温度较高，NOx排放也相对较高。 When combustion temperature lower than 1000, thermal type is little. When coal powder furnace burns anthracite or meagre coal, the high combustion temperature causes high emission of NOx.
- 燃料型NOx是燃煤锅炉最主要的NOx排放来源，通过针对性的配风方案，锅炉厂商可以将不同N元素含量的燃煤所生成的燃料型NOx控制在同一水准，即煤种中N元素的含量对锅炉出口NOx的排放影响有限。 Fuel type NOx is the main source of emission. According to the adjustment of air flow, the NOx production can be reached to similar level for different coal type.

炉型的影响 Type of furnace

- 炉型对NOx排放的影响主要体现在炉膛燃烧温度上，既热力型NOx的生成。 The type of furnace influences the combustion temperature, i.e. production of thermal type NOx.
- W型火焰炉NOx排放控制困难，即使采用低氮燃烧技术，锅炉出口NOx浓度依然高达750mg/m^3~900 mg/m^3。燃用无烟煤、贫煤的煤粉炉NOx排放与W型火焰炉类似。 NOx emission of W type furnace is difficult to control, even with the application of low NOx burner, its NOx emission at exit still up to 750~900mg.
- 燃用烟煤、褐煤的1000t级及以上机组采用低氮燃烧技术后锅炉出口NOx排放量约250mg/Nm^3，1000t级及以下约400mg/Nm^3。 NOx emission is 250mg at the exit of burner using soft coal and lignite with capacity larger than 1000t, and 400mg below 1000t.
- 流化床锅炉燃烧方式特殊，煤种适应性强，燃烧温度较低，抑制了燃烧过程中NOx的生成，锅炉出口NOx排放量一般控制在150mg/m^3~200mg/m^3。 CFB boiler’s NOx emission is 150~200mg.

脱硝技术—技术路线选择 Denitration-technology routine

煤粉炉（含W型火焰炉）优先选用SCR技术，不推荐SNCR+SCR技术

- 在煤粉炉（包括“W”型火焰炉）使用SNCR脱硝工艺，对煤粉锅炉的燃烧效率影响较大，氨逃逸不容易控制；而SCR脱硝技术基本不影响锅炉燃烧效率。 SNCR can influence coal powder furnace(including “W-type” furnace)’s combustion efficiency, while SCR have relatively little influence.

循环流化床锅炉优先选用SNCR技术

- 循环流化床锅炉燃烧方式特殊，非常适合使用SNCR技术，且SNCR装置成本较低；如使用SCR装置，需要设置多层催化剂，布置困难，成本也高。 Due to the unique combustion type of CFB boiler, SNCR is suitable and low cost. If SCR is applied to CFB boiler, multiple layers are to be settled, it is difficult to arrange and high cost.

SCR、SNCR的脱硝效率限定

- 目前SCR脱硝工艺的最高脱硝效率在90%左右，氨逃逸控制在3ppm以下； SNCR脱硝工艺一般用于循环流化床锅炉，其最高脱硝效率在70%左右，此时氨逃逸率约为8ppm。 The highest efficiency of SCR is about 90%, the escape rate of ammonia is 3ppm; the highest efficiency of SNCR is about 70%, the escape rate is 8ppm.

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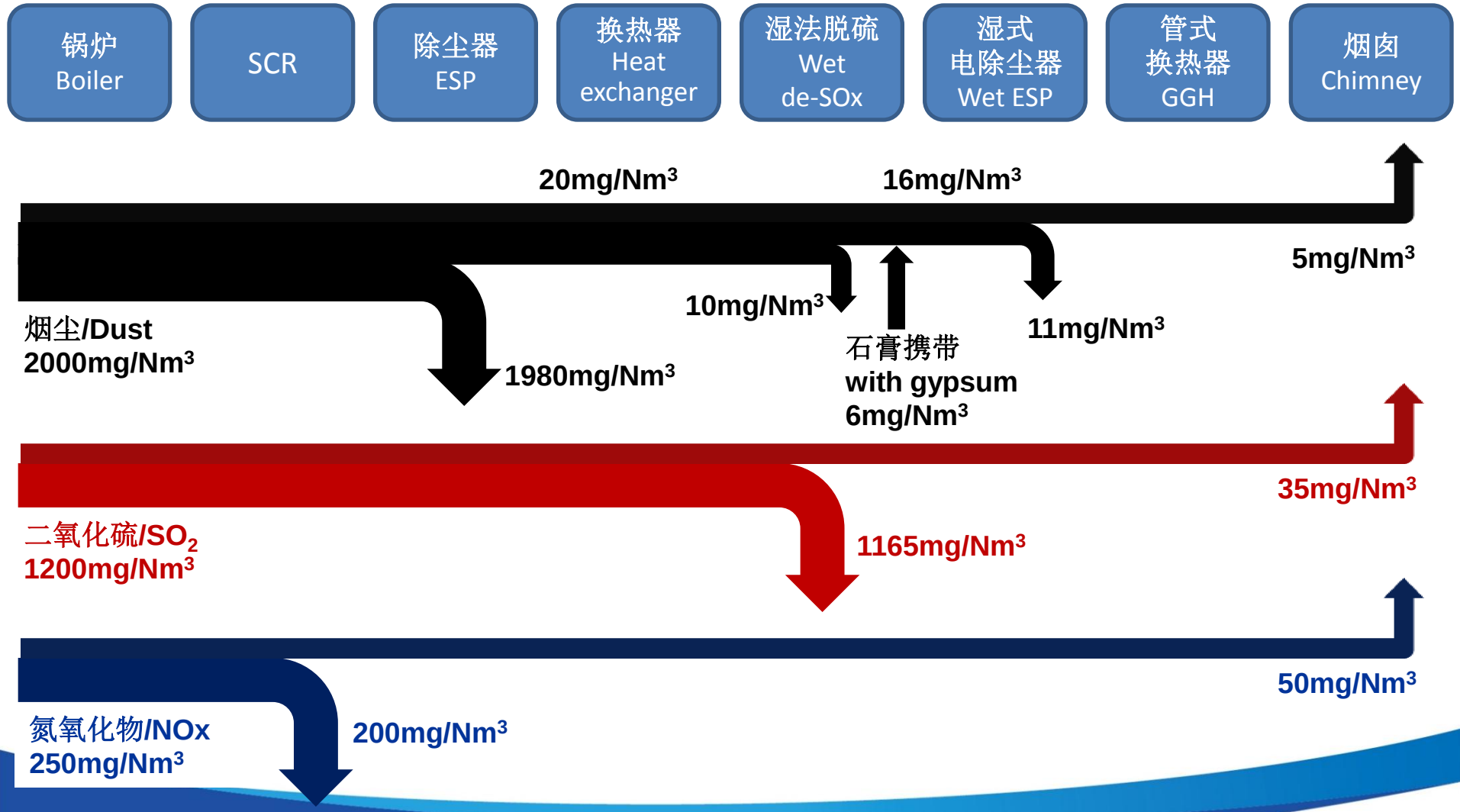
Typical Super low emission projects

超净排放典型工程
Typical super low emission projects

电力规划设计总院
Electric Power Planning & Engineering Institute

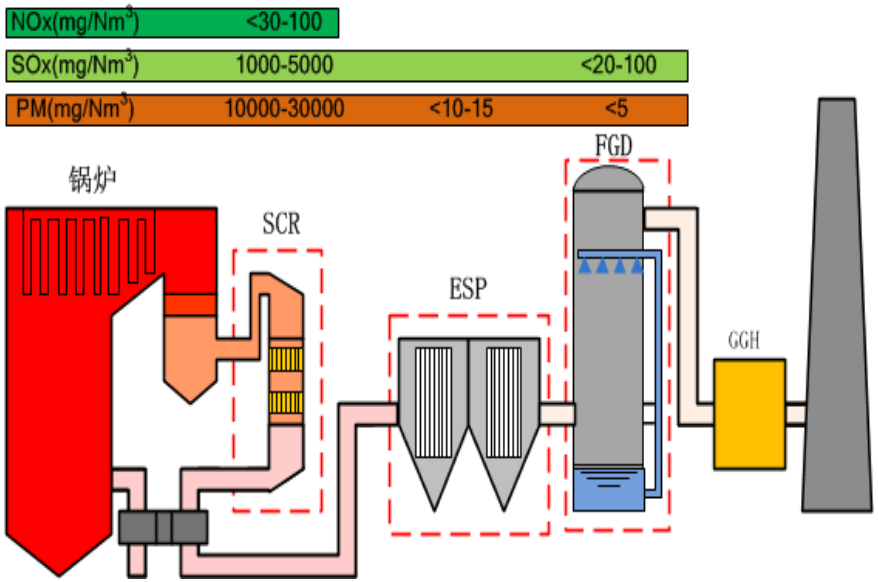
超净排放典型布置 Typical arrangement of super low emission project



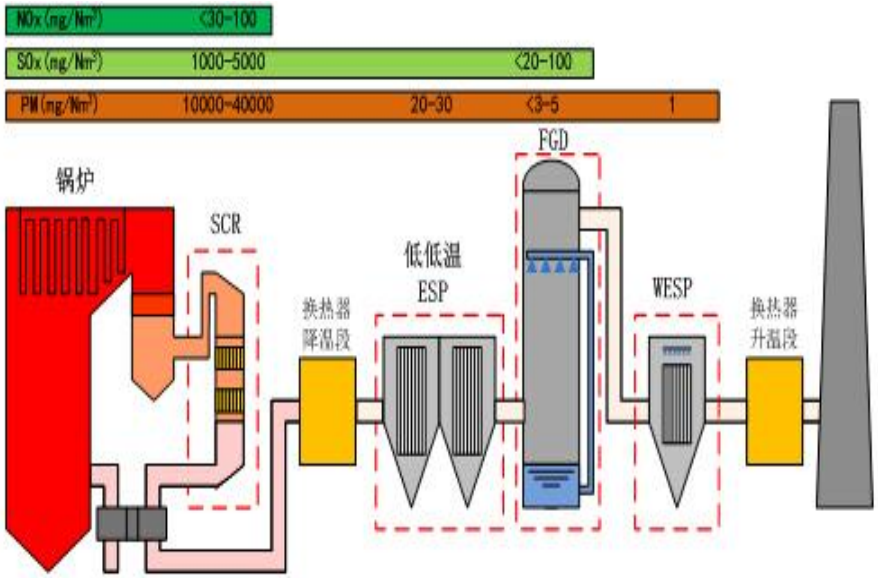
电力规划设计总院
Electric Power Planning & Engineering Institute

超净排放典型布置 Typical arrangement of super low emission project

- 目前国际上的主要技术路线
  Main technology routine worldwide:
  - 选择性催化还原 + 电除尘 + 湿法脱硫
    SCR + ESP + FGD
  - 选择性催化还原 + 低低温电除尘 + 湿法脱硫 + 湿式除尘
    SCR + low low temperature ESP + FGD + wet ESP



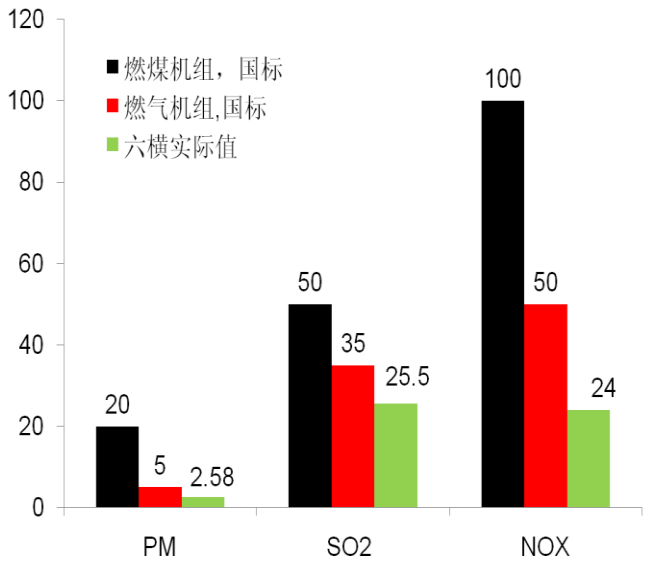
SCR + ESP + FGD



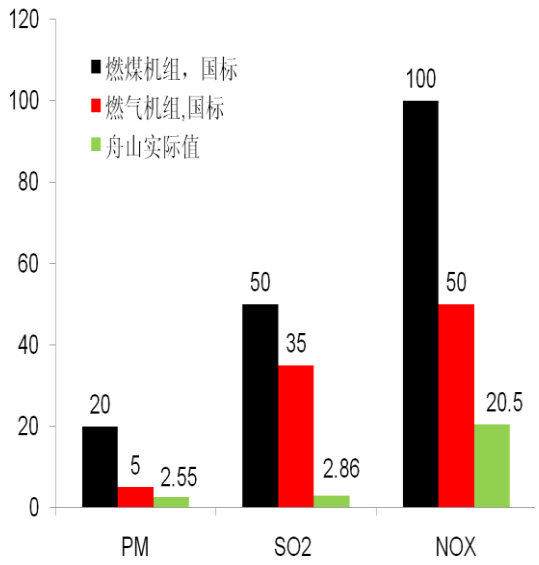
SCR + low low temperature ESP + FGD + wet ESP

典型工程 Typical projects

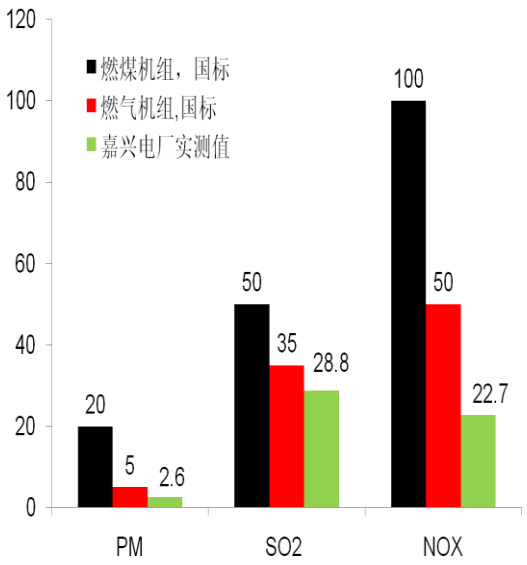
- 目前国内已有多个电厂实施了烟气超低排放
  Efficiency for denitration
  - 新建电厂：浙江浙能六横电厂（2×1000MW）（2014年6月投运）
    Newly built: Zheneng Liuheng power plant, 2×1000MW, operated on July, 2014.
  - 新建电厂：神华国华舟山电厂＃4机组（1×350MW）（2014年5月投运）
    Newly built: Shenhua Guohua Zhoushan #4 power plant, 1×350MW, operated on May, 2014.
  - 改造电厂：如浙能嘉兴电厂＃8机组（1×1000MW）（2014年5月投运）
    Upgraded: Zheneng Jiaxing #8 power plant, 1×1000MW, operated on May, 2014.



六横电厂



舟山电厂



嘉兴电厂

典型工程—舟山电厂4号机组 Typical projects-Zhoushan #4 unit

国华舟山电厂4号机组
Guohua Zhoushan #4 unit

项目	符号	单位	设计煤质	校核煤质
全水分	Mt	%	14.33	12.62
空气干燥基水分	Mad	%	7.09	6.88
收到基灰分	Aar	%	12.80	19.41
干燥无灰基挥发分	Vdaf	%	35.96	35.33
收到基碳	Car	%	59.12	54.06
收到基氢	Har	%	3.56	3.25
收到基氮	Nar	%	0.64	0.71
收到基氧	Oar	%	9.14	9.37
全硫	St,ar	%	0.41	0.58
收到基高位发热量	Qgr,v,ar	MJ/kg	23.05	21.02
收到基低位发热量	Qnet,v,ar	MJ/kg	22.00	20.07

舟山4号机组煤质资料
Coal quality of Guohua Zhoushan #4 unit

典型工程—舟山电厂4号机组 Typical projects-Zhoushan #4 unit

除尘系统设计及装备 Dust removal

- 4个常规电除尘器+1个旋转电极电除尘器+所有电场采用高频电源，出口烟尘浓度设计值≤30mg/Nm^3；在脱硫出口增设湿式电除尘器，出口烟尘浓度设计值≤5mg/Nm^3。4 sets of ESP + 1 set of rotating ESP + all electronic field with high frequency electric source, dust at the ESP exit ≤ 30mg; Equipped WESP at the exit of desulfuration tower, dust at the WESP exit ≤ 5mg.
- 实测结果表明，干式电除尘器出口烟尘浓度为14. 79mg/Nm^3，相应的除尘效率为99. 92%；海水脱硫出口烟尘浓度值为9. 1mg/Nm^3，效率38. 5%；湿式电除尘器出口烟尘浓度为3. 25mg/Nm^3，效率64. 3%。 Measured ESP exit dust is 14.79mg, ESP efficiency is 99.92%; sea water equipment exit dust is 9.1mg, efficiency is 38.5%; WESP exit dust is 3.25mg, efficiency is 64.3%.

脱硫系统设计及装备 Desulfuration

- 采用海水脱硫工艺，脱硫吸收剂采用机组凝汽器的冷却水排水，经海水升压泵升压后直接供给脱硫吸收塔，无需额外吸收剂。 Use sea water desulfuration method, draining cooling water from condenser as the absorber, supplying the absorption tower through pump.
- 脱硫效率设计值为97%，实际海水脱硫装置入口二氧化硫浓度值为909. 9mg/Nm^3，出口二氧化硫浓度值为3. 04mg/Nm^3，脱硫效率为99. 7%。 Design efficiency is 97%, measured sea water equipment inlet SO2 is 909.9mg, exit SO2 is 3.04mg, efficiency is 99.7%.

脱硝系统设计及装备 Denitration

- 采用选择性催化还原法脱硝装置，催化剂按“2+1”设计。 SCR denitration equipment, catalyst layer setting “2+1”.
- 锅炉出口氮氧化物浓度设计值为300mg，脱硝设计效率80%；锅炉出口氮氧化物浓度实测值为195. 4mg，实际脱硝效率83. 7%。 Design boiler exit NOx is 300mg, denitration efficiency is 80%; measured boiler exit NOx is 195.4mg, denitration efficiency is 83.7%.

典型工程—六横电厂1号机组 Typical projects-Liuheng #1 unit

浙能六横电厂1、2号机组
Zheneng Liuheng #1, #2 units

项目	符号	单位	设计煤质	校核煤质
全水分	Mt	%	14	9
空气干燥基水分	Mad	%	5	2
收到基灰分	Aar	%	15	22
干燥无灰基挥发分	Vdaf	%	36	40
收到基碳	Car	%	58	56
收到基氢	Har	%	3.5	3.2
收到基氮	Nar	%	0.8	0.8
收到基氧	Oar	%	8.2	8.05
全硫	St,ar	%	0.5	0.95
收到基低位发热量	Qnet,v,ar	MJ/kg	22.5	21

浙能六横电厂1号机组煤质资料
Coal quality of Zheneng Liuheng #1, #2 units

典型工程—六横电厂1号机组 Typical projects-Liuheng #1 unit

除尘系统设计及装备 Dust removal

- 4个常规电除尘器+1个旋转电极电除尘器+所有电场采用高频电源，出口烟尘浓度设计值≤15mg/Nm^3；在脱硫出口增设湿式电除尘器，出口烟尘浓度设计值≤6mg/Nm^3。4 sets of ESP + 1 set of rotating ESP + all electronic field with high frequency electric source, dust at the ESP exit ≤ 15mg; Equipped WESP at the exit of desulfuration tower, dust at the WESP exit ≤ 6mg.
- 实测结果表明，干式电除尘器出口烟尘浓度为11.8mg/Nm^3，相应的除尘效率为99.93%；脱硫吸收塔出口烟尘浓度值为13.4mg/Nm^3；湿式电除尘器出口烟尘浓度为3.1mg/Nm^3。 Measured ESP exit dust is 11.8mg, ESP efficiency is 99.93%; absorption tower exit dust is 13.4mg; WESP exit dust is 3.1mg.

脱硫系统设计及装备 Desulfuration

- 采用石灰石-石膏湿法脱硫工艺。 Limestone-gypsum wet desulfuration method.
- 脱硫效率设计值为98.6%，实际湿式脱硫装置入口二氧化硫浓度值为824.8mg/Nm^3，出口二氧化硫浓度值为14.23mg/Nm^3，脱硫效率为98.27%。 Design efficiency is 98.6%, measured FGD inlet SO2 is 824.8mg, exit SO2 is 14.23mg, efficiency is 98.27%.

脱硝系统设计及装备 Denitration

- 采用选择性催化还原法脱硝装置，催化剂按“3+1”设计。 SCR denitration equipment, catalyst layer setting “3+1”.
- 锅炉出口氮氧化物浓度设计值为330mg，脱硝设计效率84.8%；锅炉出口氮氧化物浓度实测值为213.5mg，实际脱硝效率80.3%。 Design boiler exit NOx is 330mg, denitration efficiency is 84.8%; measured boiler exit NOx is 213.5mg, denitration efficiency is 80.3%.

河北省（山东省）技术路线建议 Suggestion

项目	符号	单位	设计煤质	校核煤质
全水分	Mt	%		
空气干燥基水分	Mad	%		
收到基灰分	Aar	%		
干燥无灰基挥发分	Vdaf	%		
收到基碳	Car	%		
收到基氢	Har	%		
收到基氮	Nar	%		
收到基氧	Oar	%		
全硫	St, ar	%		
收到基低位发热量	Qnet, v, ar	MJ/kg		

河北省（山东省）典型煤质资料
Coal quality of Zheneng Liuheng #1, #2 units

电力规划设计总院
Electric Power Planning & Engineering Institute

谢 谢！

Thanks for your attention!