Staff Subcommittee on Electricity and Electric Reliability
Staff Subcommittee on Electricity & Electric Reliability and Staff Subcommittee on Clean Coal & Carbon Management

Chinese Clean Coal Technology
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Moderator: Hon Jeremy Oden, Alabama
Presenter: Dr. Peter Chen, Forest Power & Energy Holdings
Chinese Clean Coal Technology

Peter Chen, PhD
Forest Power & Energy Holdings

NARUC Summer Policy Summit
July 16, 2017
San Diego
Growth of Total Installed Electric Power Capacity in China

Ranking of Electricity Generation Capacity of China in the World

No.21 in 1949; No.8 in 1978; No.2 in 1996; No.1 in 2011
China coal power generation share by power source (2005-2016)

Percent share

<table>
<thead>
<tr>
<th>Year</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>0.82</td>
</tr>
<tr>
<td>2006</td>
<td>0.83</td>
</tr>
<tr>
<td>2007</td>
<td>0.83</td>
</tr>
<tr>
<td>2008</td>
<td>0.81</td>
</tr>
<tr>
<td>2009</td>
<td>0.78</td>
</tr>
<tr>
<td>2010</td>
<td>0.76</td>
</tr>
<tr>
<td>2011</td>
<td>0.77</td>
</tr>
<tr>
<td>2012</td>
<td>0.74</td>
</tr>
<tr>
<td>2013</td>
<td>0.74</td>
</tr>
<tr>
<td>2014</td>
<td>0.70</td>
</tr>
<tr>
<td>2015</td>
<td>0.68</td>
</tr>
<tr>
<td>2016</td>
<td>0.65</td>
</tr>
</tbody>
</table>
Energy Structure of China in 2015

- Coal: 63%
- Petroleum: 8%
- Natural gas: 8%
- Hydroelectric: 1%
- Nuclear: 2%
- Renewable: 18%
Policy of “developing large units and suppressing small ones”

Compared with large units, the coal consumption and pollutant emissions of small units are larger.

Total capacity of less than 100 thousand kW CFPP was more than 115 million kW, and more than 400 million tons of coal was consumed every year, and 5 million 400 thousand tons of CO2 was discharged.
Development of Steam Parameters of CFPP units in China

Subcritical and reheating
540°C/16.7MPa (1004°F/2422.1psi)

Super high pressure and reheating
540°C/13.7MPa (1004°F/1947.9psi)

Mid-temperature and pressure
450°C/3.82MPa (842°F/554.0psi)

High pressure
540°C/9.8MPa (1004°F/1785.3psi)

Subcritical and reheating
555°C/17.5MPa (1031°F/2538.2psi)

Super critical
540°C/23.7MPa (1004°F/3437.4psi)

Ultra super critical
600°C/605°C/28MPa (1112°F/1121°F/4061.1psi)

First domestic supercritical unit commissioned in China in 2004 and first ultra supercritical unit commissioned in China in 2006
Results of “developing large units and suppressing small ones”

- From 2005, about 100GWe units were shut down

- Shutting down inefficient small units

- Building New large capacity and high efficiency units
  - Most new units are 600-1000MW supercritical and ultra supercritical units
  - About 300GW large capacity high efficiency units has been put into operation

- Average coal consumption declining in china
  - The coal consumption of power supply was reduced from 370gce/kWh (10275BTU/kWh) in 2005 to 312gce/kWh (8665BTU/kWh) in 2016

- The coal consumption of power supply was reduced from 370gce/kWh (10275BTU/kWh) in 2005 to 312gce/kWh (8665BTU/kWh) in 2016
Results of “developing large units and suppressing small ones”

Structure of CFPP changing year by year from 2005 to 2016
Ultra Supercritical is the Direction of CFPP Development in China

Distribution of 1000MWe Ultra Supercritical Units in China

- Jiangxi: 1 unit
- Chongqing: 2 units
- Xinjiang: 2 units
- Fujian: 2 units
- Guangxi: 2 units
- Ningxia: 2 units
- Liaoning: 2 units
- Tianjin: 2 units
- Hubei: 3 units
- Anhui: 4 units
- Shandong: 5 units
- Shanghai: 4 units
- Henan: 6 units
- Guangdong: 14 units
- Zhejiang: 17 units
- Jiangsu: 18 units
Results of “developing large units and suppressing small ones”

<table>
<thead>
<tr>
<th>Year</th>
<th>Total capacity of CFPP (MWe)</th>
<th>Average coal consumption of CFPP in China (gce/kWh)</th>
<th>BTU/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>384,130</td>
<td>370</td>
<td>10275</td>
</tr>
<tr>
<td>2006</td>
<td>484,050</td>
<td>367</td>
<td>10192</td>
</tr>
<tr>
<td>2007</td>
<td>554,420</td>
<td>356</td>
<td>9887</td>
</tr>
<tr>
<td>2008</td>
<td>601,320</td>
<td>345</td>
<td>9581</td>
</tr>
<tr>
<td>2009</td>
<td>652,050</td>
<td>340</td>
<td>9442</td>
</tr>
<tr>
<td>2010</td>
<td>706,630</td>
<td>333</td>
<td>9248</td>
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<tr>
<td>2011</td>
<td>765,460</td>
<td>330</td>
<td>9164</td>
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<tr>
<td>2012</td>
<td>819,170</td>
<td>326</td>
<td>9054</td>
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<tr>
<td>2013</td>
<td>862,380</td>
<td>321</td>
<td>8914</td>
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<tr>
<td>2014</td>
<td>915,690</td>
<td>318</td>
<td>8831</td>
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<tr>
<td>2015</td>
<td>1022,740</td>
<td>315</td>
<td>8748</td>
</tr>
<tr>
<td>2016</td>
<td>1053,880</td>
<td>312</td>
<td>8665</td>
</tr>
</tbody>
</table>
Highly efficient coal power is the foundation of adopting CCS
Shanghai Waigaoqiao No. 3 Power Plant (WGQ3)
2×1000MWe USC 600°C (1112°F)
Global Performance Excellence Award

SHANGHAI WAIGAOQIAO NO.3 POWER GENERATION CO., LTD.
Shanghai, P.R.C.

WORLD CLASS
Small Manufacturing Organization

Given during the
18TH ASIA PACIFIC QUALITY CONFERENCE
Hilton Colombo Hotel, Sri Lanka
October 14 - 17, 2012

ACN. SHAN RUPRAJ
APQO President
AVF Award Chairman

CHUCK AUBREY
DR. CHARLES A. AUBREY II
GPEA / APQO Chairman

DR. H. JAMES HARRINGTON
APQO Adviser & AVF Chairman

PHASE III OF WAIGAOQIAO POWER PLANT
(2X1000 MW USC)
WAIGAOQIAO NO.3 POWER GENERATION COMPANY
SIEMENS ENERGY

GOLD Award for
Best Environmental Performance
Power Plant of the Year

Hosted by Publisher Timothy Charlton
The Prime Movers Award
for outstanding contributions to technical literature on
Thermal Electric Generating Station Equipment and Practice
This testimonial established by
The Prime Movers Committee of Edison Electric Institute
to be administered by
The American Society of Mechanical Engineers
was awarded to
Weizhong Feng
2016
The American Society of Mechanical Engineers
WGX3 Boilers (GE-Alstom)

Boilers:
Alstom licensed, tower type, USC, single reheat, single furnace, corner tangential firing and open arrangement, balanced draft, solid slag disposal, built-in separator, spiral water wall with sliding operation.
WGQ3 Turbines (Siemens)

Turbines; Siemens licensed, 1000MW, single shaft, four casings & four exhausts, double backpressures.
Advanced Energy Saving and Emission Reduction Technologies

- Energy Balanced FGD Tech., 0.378%
- New Boiler Startup Tech., 0.042%
- Comprehensive Prevention of SPE, 0.419%
- Air Preheater Sealing Tech., 0.370%
- Optimiz. of BFP and ITS System 0.101%
- Optimiz. Parameters & operation mode, 0.175%
- Optimiz. of Critical Piping Pressure Drop 0.125%
- Optimiz. of Turbine Backpressure, 0.107%
- Energy Saving Freq. Regulation Tech., 0.139%
- General App. of Extraction Energy Tech., 0.433%
- Elasticity App. of Extraction Energy Tech., 0.150%
- Other Energy Saving Tech., 0.181%
- Comprehensive Prevention of SPE, 0.419%
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- Elasticity App. of Extraction Energy Tech., 0.150%
- Other Energy Saving Tech., 0.181%
Generalized Regeneration Technology

- Supplementary heating of feedwater
- Steam generator
- Furnace
- Heating the air
- Heating fuel (mixture of coal, air, and water steam)
- Flue gas (loss constant)
- Steam (utilization)
- Turbine
- Generator
- Condenser
Energy balanced FGD technology

**Traditional FGD system**

- Air leakage < 4%
- Total flow of flue gas reduced by 19.4%
- Single ID Fan operation in low load

**Energy balanced FGD system**

- Low temperature flue gas recovery system (Develop special heat exchanger to replace traditional GGH)

- Control system for low temperature corrosion of heat transfer tube
Tube Blocked by Oxide Scales

Turbine Blades Eroded by Solid Particles

Bypass Valve Plug Eroded by Solid Particles

SPE (Solid Particle Erosion)
The oxide deposits in the last superheater of a 1000MW USC boiler in Zhejiang province.
The inside of reheater tubes in Waigaoqiao II 900MW after one operation.
The boiler tube after 30 months operation in WGQIII.
The boiler tubes of WGQ3 after 30 months running.

The inside of reheater tubes.
WGQ3 turbine blading after 8 years operation
Extending life time of SCR catalyst

Design life time of catalyst is 16,000 hours, actual operation time is more than 60,000 hours. Efficiency stays at >90%, with insignificant efficiency decline.
Comparison of cold startup between WGQ2 900MW unit and WGQ3
The effect of generalized regeneration technology

1. **Reduction of coal consumption**
   - Design coal consumption: 291.5 g/KWh (at rated load condition)
   - Actual coal consumption: 264.2 g/KWh (at rated load condition)
   - Reduction of flue gas and fly ash: 9%

2. **Reduction of air preheater leakage**
   - Design leakage of air preheater: 6%
   - Actual leakage of air preheater: <4%
   - Reduction of flue gas: >2%

3. **Low oxygen Combustion**
   - Design oxygen at boiler exit: 3.5% (at rated load condition)
   - Actual oxygen at boiler exit: 2% (at rated load condition)
   - Reduction of flue gas: 8.4%

4. **Low-low temperature ESP**
   - Design inlet flue gas temperature of ESP: 403K
   - Actual inlet flue gas temperature of ESP: 373K
   - Reduction of flue gas velocity: 7.5%

Total reduction of flue gas flow: >19.4%,
Total reduction of flue gas velocity: >26.9%,
High efficiency and full load SCR system

- Total flow of flue gas reduced by more than 19.4%
- SCR catalyst operates in full load
- Extended life of SCR catalyst

NOx 17mg/Nm³
Energy balanced FGD technology

Effect:

Metallographic analysis shows that the sulfur corrosion can be neglected

Improve efficiency by 0.378%, saving 30000 tons of specific coal each year

Reduce water consumption of FGD scrubber by more than 45t/h
Energy-saving and ultra-low emission technology
A series of high-efficiency and energy-saving de-dust technologies

High frequency power supply is adopted, not only improve ESP efficiency, but also reduce power consumption.

Effect:
- Power consumption of the ESP reduces by 70%, saving 9.07 GWh power annually.
A series of high-efficiency and energy-saving de-dust technologies

The low dust emission of Shanghai WGQ NO.3 CFPP

- Put into operation
- Decrease flue gas speed
- High frequency power supply
- With flue gas cooler
- After FGD

Outlet of ESP

- 30~50 mg/Nm³
- 20~25 mg/Nm³
- 12~15 mg/Nm³
- ~7 mg/Nm³
- ~0.74 mg/Nm³
Emissions of Shanghai WGQ NO.3 clean CFPP

<table>
<thead>
<tr>
<th></th>
<th>EU</th>
<th>JPN</th>
<th>USA</th>
<th>PRC (coal power)</th>
<th>PRC (gas power)</th>
<th>WGQ3</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx (mg/Nm³)</td>
<td>200</td>
<td>200</td>
<td>135</td>
<td>100</td>
<td>50</td>
<td>17</td>
</tr>
<tr>
<td>SO₂ (mg/Nm³)</td>
<td>200</td>
<td>172</td>
<td>184</td>
<td>50</td>
<td>35</td>
<td>18</td>
</tr>
<tr>
<td>Dust (mg/Nm³)</td>
<td>30</td>
<td>40</td>
<td>20</td>
<td>20</td>
<td>5</td>
<td>0.74</td>
</tr>
</tbody>
</table>
Rated Efficiency

<table>
<thead>
<tr>
<th></th>
<th>Original Design</th>
<th>After Long Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>WGQ NO.3 CFPP</td>
<td>42%</td>
<td>46.5%</td>
</tr>
<tr>
<td>Same Type Unit</td>
<td>42%</td>
<td>41%</td>
</tr>
</tbody>
</table>
**Energy Saving**  
A series of energy-saving technologies, including: innovative boiler start up, generalized regeneration technology, centralized frequency variable power system, and energy-saving emission reduction technology.

Improve the existing unit efficiency from 42% to 46.5% in full load.

House power rate has been reduced from 3.5% to less than 2% (SCR and FGD included)
<table>
<thead>
<tr>
<th>Efficiency Preservation</th>
<th>Prevent the formation of oxide skin and solve the problem of solid particle erosion on turbine blades.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solve the problem of blocking and corrosion in cool end of air preheater.</td>
</tr>
<tr>
<td></td>
<td>Net efficiency is 5.5% higher than that of the same type unit and does not decline after long operation.</td>
</tr>
</tbody>
</table>
Ensuring Safety

FCB safety technology

Avoid boiler tube explosion due to the steam side oxidization

Water pump optimization, eliminate the disconnection and juxtaposition between multiple pumps
<table>
<thead>
<tr>
<th>Environmental Protection</th>
<th>Low oxygen combustion, high efficiency combustion, reduce the total amount of flue gas</th>
</tr>
</thead>
</table>

Dust, NOX and SO2 emission:
0.74mg/Nm$^3$, 17mg/Nm$^3$ and 18mg/Nm$^3$
Ensuring Elasticity

The minimum boiler load is 8.24% with stable combustion under oil breaking conditions.

For retrofitting units, the stable load of the unit can be lower than 20%.
Development and Application of Advanced CFPP Technology

Ultra Supercritical Units

Subcritical Units

Tongshan
Cao Feidian
Fuyang

Anhui Pingshan Phase II

Xuzhou
Tongshan Project (2*1000MW USC)

Technology implementation in existing Tongshan HuaRun Power Plant (2*1000MW USC).

Siemens and GE commissioned to conduct the performance test for the unit.

Heat rate improved from 7970BTU/kWh to 7665BTU/kWh.

Coal consumption of power supply reaches to 276 g/kWh based on original design parameter of 287 g/kWh.

<table>
<thead>
<tr>
<th>Performance test load rate</th>
<th>100%</th>
<th>80%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance test number</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Boiler efficiency</td>
<td>95.52 %</td>
<td>95.68 %</td>
<td>95.88 %</td>
</tr>
<tr>
<td>Performance test fuel quantity</td>
<td>99.42 kg/s</td>
<td>83.78 kg/s</td>
<td>51.95 kg/s</td>
</tr>
<tr>
<td>Total load during performance test</td>
<td>1007.4 MWe</td>
<td>804.1 MWe</td>
<td>542.7 MWe</td>
</tr>
<tr>
<td>Power consumption of auxiliary machine during performance test;</td>
<td>34.18 MWe</td>
<td>28.87 MWe</td>
<td>24.07 MWe</td>
</tr>
<tr>
<td>Net load during performance test</td>
<td>973.2 MWe</td>
<td>775.2 MWe</td>
<td>518.6 MWe</td>
</tr>
<tr>
<td>Coal consumption of power supply during Performance test</td>
<td>273.2 g/kWh</td>
<td>274.5 g/kWh</td>
<td>280.4 g/kWh</td>
</tr>
<tr>
<td>Power supply efficiency during performance test</td>
<td>45.0 %</td>
<td>44.8%</td>
<td>43.9 %</td>
</tr>
<tr>
<td>Power supply efficiency before reformation (2013)</td>
<td>43.5 %</td>
<td>42.5 %</td>
<td>40.7 %</td>
</tr>
<tr>
<td>Improvement of the power supply efficiency after the reformation,</td>
<td>1.5%</td>
<td>2.3%</td>
<td>3.2%</td>
</tr>
</tbody>
</table>
Caofeidian Project (2*1000MW)

Caofeidian project plans to build two units of single-shaft arrangement with single reheat cycle; With Advanced Technologies, the efficiency will reach 46.53%, exceeding the level of China's double reheat units in 1000MW.
Why is China developing double reheating Technology?

- Compared with the primary reheating technology, the efficient of the double reheating technology is higher by 2% and the CO2 emission reduces by about 4%.

- It is expected that the 700°C (1292°F) ultra supercritical technology will take about 10 years to demonstrate and fully commercialize.
Challenge of conventional double reheat design

For conventional double reheat technology, the main steam and reheat steam piping would be routed long distance between the boiler and turbine ~ 200m for a single pipe (1000MW unit).

Working medium’s flow path of double reheat unit with conventional layout
Pingshan Phase II Project (1*1350MW)

- Double reheat + Elevated T-G layout

- High positioned turbine generator train
  (the platform is about 85 meters high)

- The platform for conventional turbine generator train

- Tower type of boiler
HR = 6947 kJ/kWh

unit net efficiency is 48.92%.
Pingshan Phase II Project (1*1350MW)

Some optimization was made, and the results calculated by Siemens list as follows.

<table>
<thead>
<tr>
<th>Item</th>
<th>Result</th>
<th>Impact on Δheat rate kJ/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP inlet pressure</td>
<td>3.9 bar -&gt; 3 bar</td>
<td>+10</td>
</tr>
<tr>
<td>Main steam pressure</td>
<td>300 bar -&gt; 330 bar</td>
<td>-20</td>
</tr>
<tr>
<td>Main steam temperature</td>
<td>600°C -&gt; 610°C</td>
<td>-13</td>
</tr>
<tr>
<td>2nd HRH temperature</td>
<td>620°C -&gt; 630°C</td>
<td>-9</td>
</tr>
<tr>
<td>1st HRH temperature</td>
<td>610°C -&gt; 620°C</td>
<td>-10</td>
</tr>
<tr>
<td>Feed water temperature</td>
<td>317°C -&gt; 320°C</td>
<td>-4</td>
</tr>
<tr>
<td>optimized LP extraction and use 2LSB design</td>
<td>~-10</td>
<td></td>
</tr>
<tr>
<td>Optimization on Cycle**</td>
<td>~-10</td>
<td></td>
</tr>
</tbody>
</table>

**Sum**

-65

Remarks:

the design net efficiency can be improved to **49.8%**
## Pingshan Phase II Project (1*1350MW)

Efficiency related indicators and CO2 emission levels (design condition)

<table>
<thead>
<tr>
<th>Project</th>
<th>WGQ3 power plant</th>
<th>Pingshan phase II 1350 MW unit (latest research)</th>
<th>Elevated T-G unit with 700℃.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The design coal consumption rate g/kWh</td>
<td>264.16</td>
<td>246.66</td>
<td>231.76</td>
</tr>
<tr>
<td>The design net efficiency</td>
<td>46.50%</td>
<td>49.80%</td>
<td>53.00%</td>
</tr>
<tr>
<td>Heat rate BTU/kWh</td>
<td>7338</td>
<td>6852</td>
<td>6438</td>
</tr>
<tr>
<td>The design CO2 emission (gross) g/kWh</td>
<td>666.87</td>
<td>622.69</td>
<td>588.21</td>
</tr>
<tr>
<td>The design CO2 emission (net) g/kWh</td>
<td>713.23</td>
<td>665.98</td>
<td>625.75</td>
</tr>
</tbody>
</table>

### Notes:

1. **The design CO2 emission (gross)**--namely kg CO2/MWh of gross power output at design condition;
2. **The design CO2 emission (net)**--namely kg CO2/MWh of net power output at design condition;
3. The coal consumption rate and net efficiency above are calculated with the calorific value of **standard coal 29307.6 kJ/kg**.
# Pingshan Phase II Project (1*1350MW)

## Efficiency related indicators and CO2 emission levels (annual average load rate of 80%)

<table>
<thead>
<tr>
<th>Project</th>
<th>WGQ3 power plant</th>
<th>Pingshan phase II 1350 MW unit (latest research)</th>
<th>Elevated T-G unit with 700℃</th>
</tr>
</thead>
<tbody>
<tr>
<td>The annual average coal consumption rate g/kWh</td>
<td>276.02</td>
<td>251.71</td>
<td>236.22</td>
</tr>
<tr>
<td>The annual average net efficiency</td>
<td>44.50%</td>
<td>48.80%</td>
<td>52.00%</td>
</tr>
<tr>
<td>Heat rate BTU/kWh</td>
<td>7667</td>
<td>6992</td>
<td>6562</td>
</tr>
<tr>
<td>The annual average CO2 emission (gross) g/kWh</td>
<td>696.81</td>
<td>635.44</td>
<td>599.53</td>
</tr>
<tr>
<td>The annual average CO2 emission (net) g/kWh</td>
<td>745.25</td>
<td>679.62</td>
<td>637.79</td>
</tr>
</tbody>
</table>

**Notes:**

1. **The annual average CO2 emission (gross)**--according to the definition of CO2 emission standard by American EPRI, namely kg CO2/MWh of gross power output at annual average load rate of 80%;

2. **The annual average CO2 emission (net)** --namely kg CO2/MWh of net power output at annual average load rate of 80%;

3. The coal consumption rate and net efficiency above are calculated with the calorific value of **standard coal 29307.6 kJ/kg**.
Fuyang Project (2 × 660MW)

- Principle: The whole single shaft turbine is elevated and the condenser is at conventional level.
- Effect: The unit efficiency is expected to be about 50%.
The reformation technology of the high temperature subcritical unit is to keep the unit pressure at the subcritical level (about 17MPa) but improving the temperature of the main steam and reheat steam to about 600°C (1112°F).

- Reform content
  - Super heater and reheater, HP and IP pressure cylinders, and other main steam pipes and valves, hot steam pipes and valves, high and medium pressure by-pass valves.
  - Extent of reform is relatively small: the wall thickness of the pipe can be controlled and the pressure is unchanged.
<table>
<thead>
<tr>
<th>Challenges for coal power in ultra-low load and flexible operation:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ultra-low load operation</strong></td>
</tr>
<tr>
<td>Challenge for safety</td>
</tr>
<tr>
<td>Challenge for efficiency</td>
</tr>
<tr>
<td>Challenge for environmental protection</td>
</tr>
<tr>
<td><strong>Flexible operation</strong></td>
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<td>Challenge for safety</td>
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<tr>
<td>Challenge for efficiency</td>
</tr>
<tr>
<td><strong>Challenge for safety</strong></td>
</tr>
<tr>
<td>Unstable combustion</td>
</tr>
<tr>
<td>Water-wall slagging</td>
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<tr>
<td>Hydrodynamic instability</td>
</tr>
<tr>
<td>Air preheater Clogging</td>
</tr>
<tr>
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<tr>
<td>High auxiliary power consumption</td>
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<tr>
<td><strong>Challenge for efficiency</strong></td>
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<tr>
<td>Unstable combustion</td>
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<td><strong>Challenge for environmental protection</strong></td>
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<tr>
<td>Stress problem with Water-wall &amp; heating surface and valve erosion</td>
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<td>Throttling loss</td>
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Ensuring the elasticity of CFPP
---Ultra low load stable operation technology

- Supplementary heating of feedwater
- Steam generator
- Furnace
- Heating fuel
  (mixture of coal, air and water steam)
- Flue gas
  (loss constant)
- Steam (utilization)
- Turbine
- Generator
- Condenser
Ultra High Efficiency and Low Emission CFPP Technologies

Energy Saving
- Net efficiency close to 50%
- Heat rate 6852 BTU/kwh

Efficiency Preservation
- Net efficiency 5.5% higher than that of the same type unit after long run

Ensuring Safety
- FCB safety technology
- Avoid boiler tube explosion due to the steam side oxidization

Environmental Protection
- Dust: 0.74 mg/Nm³; SO2: 18 mg/Nm³; NOX: 17 mg/Nm³
- CO2 emission 623 g/kWh

Ensuring Elasticity
- The minimum boiler load 8.24%, under oil breaking conditions
- Stable combustion and high efficiency in low load
THANK YOU!

Peter Chen, PhD

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Staff Subcommittee on Electricity and Electric Reliability