State of the Art
Combined Cycle &
Steam Power Plants

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Director Solutions Marketing 50Hz

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State of the Art Combined Cycle & Steam Power Plants

- Market Environment
- What means 'State of the Art'?
- Energy Efficiency and Emissions
- State of the Art Combined Cycle Power Plant and its relating Gas Turbine
- State of the Art Steam Power Plant and its relating Steam Turbines
- Outview
Renewables are gaining in importance – but fossil fuels will continue to be the mainstay

- Overestimation of demand, impacts of oil price crises
- Steep rise in power demand
- US-market bubble replaced by extraordinary China/Middle East
- Market boom in S/E Asia replaced by US-boom
- Slow down due to recession, lower consumption growth, high order backlog

Drivers, Uncertainties
- Economy growth
- Energy prices
- Ecology awareness
- Power plant types
- Commodity prices
- Liberalization
- Customer behavior
- Replacements
- Regional markets
- Grid extension
- Production capacity
Siemens Energy Sector – Answers for energy supply

Energy products and solutions - in 6 Divisions

- Oil & Gas
- Fossil Power Generation
- Renewable Energy
- Energy Service
- Power Transmission
- Power Distribution

today's presentation
<table>
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<th>Topic</th>
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<td>Market Environment</td>
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<td>What means ‘State of the Art‘?</td>
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<td>Outlook</td>
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### Siemens Energy Sector – Answers to the multifaceted market requirements

#### Influencing factors

- Increasing energy demand worldwide
- Power supply in urban and rural areas
- Climate change
- Scarcity of fossil fuels

#### Energy market requirements

- **Reliable supply**
  - Fast response to load changes
  - Provision of base-, intermediate- and peak-load generating capacities
  - Long-distance transmission of large amounts of electricity, grid stability
  - Technologies for difficult-to-access and unconventional oil and gas deposits

- **Climate and environmental protection**
  - Reduction of CO$_2$, NO$_x$, SO$_x$ etc.
  - Efficient use of fossil fuels
  - Low-loss energy transport
  - Noise control and environmental protection

- **Cost-effectiveness**
  - High efficiency
  - Low lifecycle costs
  - High security of investment / profitability
  - Low O&M and service costs

#### Energy Sector – Products and solutions

- High-performance, reliable gas turbines for fast response to load changes
- High-voltage DC transmission (HVDC), reactive-power compensation
- Whisper transformers, energy automation systems
- Systems for underwater recovery of oil and gas, unmanned pumping stations

- High-efficiency power plants (CCPP)
- Renewables: wind (on- and offshore), solarthermal
- HVDC and ultra high-voltage systems
- Whisper transformers, gas-insulated lines
- CO$_2$ compressors for Carbon capture and storage (CCS)

- High-efficiency CC and coal-fired power plants
- Switchgear with 25-year maintenance intervals
- Cost-saving service solutions
- Highly profitable E-LNG solutions (Electric Liquefied Natural Gas)
State of the Art Combined Cycle & Steam Power Plants

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Energy Efficiency and Carbon Capture & Sequestration (CCS) are key solutions to reaching emission reduction targets.

<table>
<thead>
<tr>
<th>Source:IEA* alternative policy scenario</th>
<th>IEA* reference scenario</th>
<th>IEA* alternative policy scenario incl. CCS</th>
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<tbody>
<tr>
<td>EU emissions, Gt CO₂/year, 2030</td>
<td></td>
<td></td>
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<tr>
<td>Energy efficiency</td>
<td></td>
<td></td>
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<tr>
<td>Renewables’ growth</td>
<td></td>
<td></td>
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<tr>
<td>Other</td>
<td></td>
<td></td>
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<tr>
<td>CCS potential</td>
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It is globally accepted by now that CCS is indispensable for reaching global carbon emissions reduction targets.
There is a lot of efficiency improvement potential for the averagely installed Gas and Steam Power Plant.
Efficiency is key driver: Siemens technology efficiency milestones

Steam Power Plants
- Reference plant Germany, 600 MW: 46%

Combined Cycle Power Plant
- CCPP Irsching 4, 530 MW: 60%

Integrated Gasification Plant
- Puertollano, 320 MW: 45% (*)

Future potentials
- Puertollano (*)
- unspecified plant in Europe

Development of efficiency (net)

Source: Siemens Energy ST MOP

*) coal quality depending
- Market Environment
- What means 'State of the Art'? 
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Our basis for State of the Art Power Plants: Reference Power Plants (RPP) = pre-engineered Power Plants

<table>
<thead>
<tr>
<th>Operating Costs</th>
<th>Plant Operation</th>
<th>Financials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Price</td>
<td>Power Output</td>
<td>Investment Volume</td>
</tr>
<tr>
<td>Fuel Price</td>
<td>Efficiency</td>
<td>Payment Schedule</td>
</tr>
<tr>
<td>Personnel Costs</td>
<td>Availability/Reliability</td>
<td>Lead time</td>
</tr>
<tr>
<td>Consumables</td>
<td>Emissions</td>
<td>Debt/ Equity Ratio</td>
</tr>
<tr>
<td>Insurance</td>
<td>Load Regime</td>
<td>Interest Rate</td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
<td>Income Tax</td>
</tr>
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Increased customer value by optimised key factors
**Example - Fossil power generation:**

**Combined cycle power plants**

Combined-cycle power plants belong to the most energy efficient fossil-fired power generators. The new gas turbine from Siemens in Bavarian town Irsching is expected to set a new efficiency record: over 60 percent.

<table>
<thead>
<tr>
<th>Key features</th>
<th>Customer value</th>
</tr>
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<tbody>
<tr>
<td>High efficiency due to combination of gas and steam turbines</td>
<td>Low fuel consumption*</td>
</tr>
<tr>
<td>Further efficiency enhancements possible thanks to higher combustion temperatures and innovative turbines</td>
<td>Low operating costs*</td>
</tr>
</tbody>
</table>

- Only 345 g CO2-emissions per kilowatt hour, compared to 578 in average power generation worldwide
- Significant emissions reduction anticipated (gas turbine Irsching)
- High flexibility and availability

*Compared to conventional fossil-fired power plants

2% Pt. efficiency increase => CO₂ saving compared to 9.500 cars with 20.000 km/a
The world's biggest Gas Turbine and the relating most efficient Combined Cycle Power Plant (CCPP)

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<table>
<thead>
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<tbody>
<tr>
<td>Gas turbine</td>
<td>SGT5-8000H</td>
</tr>
<tr>
<td>Steam turbine</td>
<td>SST5-5000</td>
</tr>
<tr>
<td>Generator</td>
<td>SGen5-3000W</td>
</tr>
<tr>
<td>Fuel</td>
<td>nat. gas, #2</td>
</tr>
<tr>
<td>GT / CC output</td>
<td>340 / 530 MW</td>
</tr>
<tr>
<td>GT / CC efficiency</td>
<td>&gt; 39% / &gt; 60 %</td>
</tr>
<tr>
<td>Pressure ratio</td>
<td>19.2 : 1</td>
</tr>
<tr>
<td>Exhaust mass flow</td>
<td>820 kg/s</td>
</tr>
<tr>
<td>Exhaust temperature</td>
<td>625 °C</td>
</tr>
<tr>
<td>Turn down</td>
<td>50%</td>
</tr>
<tr>
<td>HRSG/WS-Cycle</td>
<td>3Pr-RH, Benson</td>
</tr>
<tr>
<td></td>
<td>600°C / 170 bar</td>
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</tbody>
</table>
The world biggest Gas Turbine
SGT5-8000H power data in comparison

1 Gas Turbine blade = 10 Porsche

1 Gas Turbine = 1100 Porsche or 13 Boeing 747-400 engines

1 CCPP = 1715 Porsche or 20 Boeing 747-400 engines
Some State of the Art Gas Turbine features of the SGT5-8000H

- High cycling capability due to advanced blade cooling system
- Advanced ULN combustion system
- Evolutionary 3D-compressor blading
- Proven rotor design, Hirth serration and central tie rod
- Four stage turbine with advanced materials and thermal barrier coating
- ≥ 60% Combined Cycle efficiency
- Integrated combined cycle process for economy and low emissions
Technology Lever: Combustor design

Combustion Chamber

- silo
- annular
- can annular

Burner Type

- Diffusion Burner: >250ppm NOx
- Hybrid Burner: 15-25ppm NOx
- DLN/ULN Burner: <15-25ppm NOx

example: 8000H Combustor
Technology Lever:
Cooling & Leakage Air Reduction

example: Hydraulic Clearance Optimization

example: tile holders for ceramic heat shields
Technology Lever:
Aerodynamical blade design compressor and turbine

Blade profile

3D-Aero Blading Design
example: 4000F turbine blade

Blade shape

aus Cumpsty, N.A.: Compressor Aerodynamics
Technology Lever:
Mechanical turbine blade design

Cooling

- no cooling
- convective cooling
- impingement cooling
- film cooling

Base Material

- IN738
- IN939
- IN792 DS
- 1st Gen. SX
- 2nd Gen. SX
- U700

Coatings

- MCrAlY: SICOAT
- 2231TBC: e.g. ZrO$_2$+Y$_2$O$_3$
- Coating Technologies: APS, EB-PVD

Manufacturing

- Casting:
  - conventional
  - directional solidification
  - single crystal casting

APS: Advanced Plasma Spray; EB-PVD: Electron Beam Physical Vapor Deposition

example: 4000F turbine blade
Technology Development Success Stories: Advanced High Temperature Coating Systems

- New Low K TBC Benefit
- Allowable Hot Gas Temperature
- Film Cooling
- Convective Cooling
- 8YSZ TBC
- Siemens “Class 1” low K TBCs 1st generation implemented and in production
- Market Environment
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State of the Art:
Some References for High Steam Parameters

Isogo, Japan
1x600 MWel / Main Steam: 251 bar / 600 °C
Reheat Steam: 610°C, Condenser: 0.0507 bar
in Operation since 2002

Niederaussem, Germany
1x1025 MWel / Main Steam: 265 bar/576°C
Reheat Steam: 600°C, Condenser: 0.0291/0.0368 bar
in Operation since 2003

Waigaoqiao 1+2, China
2x900 MWel / Main Steam: 250 bar / 538°C
Reheat Steam: 566°C, Condenser: 0.049/0.0368 bar
in Operation since 2004

Yuhuan, China
4x1000 MWel / Main Steam: 262.5 bar / 600 °C
Reheat Steam: 600°C, Condenser: 0.054/0.044 bar
in Operation since 2007

Kogan Creek, Australia
1x750 MWel / Main Steam: 250 bar / 540°C
Reheat Steam: 560°C, Condenser: 0.2 bar ACC
in Operation since 2007

Waigaoqiao 3, China
1x1000 MWel / Main Steam: 270 bar / 600°C
Reheat Steam: 600°C, Condenser: 0.054/0.044 bar
planned Operation in 2009

Largest Ultra-Supercritical Steam Turbines recently built by Siemens with excellent operating records
...the relating State of the Art Steam Turbines

SST-6000

Rating 50 Hz / 60 Hz
300 MW to 1200 MW

Steam conditions SPP
up to 300 bar / 600°C / 600°C
up to 4350 psi / 1110°F / 1110°F
Optimized blades and increased exhaust areas for highest efficiencies

HP & IP blades
- Interlocked blades
- Titanium forged blades
- Interlocked shroud
- Midspan snubber
- Side entry roots

3D blading
- Modern 3D blade
- ~ 2%
- Earlier blading

Last row blades
- Interlocked blades
- Titanium forged blades
- Interlocked shroud
- Midspan snubber
- Side entry roots

Free standing blades
- Steel forged blades
- Side entry roots
Highlights and design details
Additional measures against erosion

Design features

- Proven methodology for prediction of erosion impact and selection of optimum protection level and relevant features (not all features are applied at the same time)
- Minimized trailing-edge thickness for reduced droplet size
- Flame hardening or laser hardening of moving-blade inlet edge
- Moisture-extraction slots at outer flow contours
- Hollow guide vanes with moisture-extraction slots on blade surface
- Hollow guide vanes with internal heating system to evaporate surface moisture

Customer benefits

- Improved reliability and life time
- Reduced ageing
- Optimum protection level for each application
Sealing – labyrinth with abradable coating

Design features

- Coating applied to standard seal segments (thickness about 0.6 mm)
- Reduced leakage flow due to reduced clearances (about 20% less than uncoated labyrinth)
- Favorable coating behavior during contact: fin cuts groove into coating without damage to fin or significant heating, at negligible torque
- Suitable for large pressure drops
- Increased clearance between hard parts for additional operating safety
- Applicable to various types of seal segments, especially
  - balance piston
  - dummy piston

Customer benefits

- Increased efficiency and power output
- Increased operational safety
- Proven design
Sealing – brush seals

Design features

- Bristle pack allows very tight clearances
- 50-70% reduction in leakage flow compared to standard labyrinth
- Bristles give way in transient operation
- Backing plate of brush element is positioned further away from rotating parts than standard seal fins to increase operating safety
- Brush seal is used as add-on in current labyrinth seals
- Used for low and moderate pressure drops, i.e.
  - Gland seal (inserted in segments, HP/IP)
  - Gland seal (inserted in casing, LP)

Customer benefits

- Increased power output and efficiency
- No impact on operational safety
Market Environment

What means 'State of the Art'?

Energy Efficiency and Emissions

State of the Art Combined Cycle Power Plant and its relating Gas Turbine

State of the Art Steam Power Plant and its relating Steam Turbines

Outlook
Steam Turbines for 700°C SPP – the next generation of big steam power plants

Goal:
- > 50% net efficiency
- 700°C, 350 bar

State of the art:
- 46% net efficiency
- 600°C, 250 bar

approx. 7% less fuel consumption and CO₂

The way there:
- New materials and design concepts
  (innovative components: HP and IP turbines and valves)
- Component test facility COMTES700 at Scholven since 2005
- Engineering study NRWPP700 since 2006
  (financing through NRW and 700°C partners)
- Demo plant 550 MW
## Siemens preferred solutions for CO₂ capture

**IGCC / Precombustion carbon capture**
- Gasification technology with multi-fuel capability for new power plants
  - Technology "ready for implementation"
  - Alternative route for chemical / fuel production, hydrogen economy
  - Mastering higher technological and contractual complexity with "Siemens phased project execution offer".

**Post-combustion carbon capture**
- Scalable market introduction, Demoplants with slipstreams, minimize upgrade risk in process trains
- Enhancement potential for solvents, scrubbing process and for integration into the power plants
- For retrofit and new fossil fired power plants
- Siemens develops amino acid salt based process and has established partnership for aqueous ammonia process.

Siemens solutions will be ready for the implementation in the upcoming CCS demonstration projects.

More on this topic will be covered by a later lecture today at 16:00
Many thanks for your kind attention

Dr. Harald Kurz
Siemens Energy Sector
There are many measurements which gives indications for ‘State of the Art’...

**Business Drivers**
- Engine Performance
- Reliability / Availability / Maintainability (RAM)
- Market / Competitiveness

**Customer Requirements**
- Power
- Efficiency
- Emissions
- First Cost
- Life Cycle Cost
- Capital Cost
- Maintenance Cost
- Operational Costs
- Time-to-Market
- Operational Flexibility
- Fuel Flexibility
- Cycling Capability
- Upgradeability
- Regulatory Compliance
- Product Integrity
- Robust Design
- Proven Design Features

**Core Competencies**
- Aerodynamics
- Coatings
- Code Development
- Combustion
- Diagnostics
- Dynamic Integrity
- Engine Operations
- Heat Transfer / Cooling
- Materials
- Mechanical Integrity
- NDE Technology
- Probabilistic Design
- Sealing Technology
- Secondary Air Systems
- Thermodynamics
SGT5-8000H first turbine stage
improved design for **highest efficiency**

- Largest single-crystal stage to date
- Contoured shroud of vane
- Thin wall casting
- Airfoil and shrouds are highly impingement-cooled
- Highly film-cooled airfoils
State of the Art requires high Operational Flexibility...

This range of operation requires flexibility

• Faster starts
• Increased turndown
• High part load performance

Our Solution

Air Cooled engine with Less Complexity
No external engine dependencies for cooling
No ties to water-steam cycle for cooling
IF THE ENGINE IS TURNING, THERE IS COOLING
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