

# Coal-fired power plants – flexibility options and challenges

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Sustainability Credentials of Coal and its Role  
in the UN, Geneva, 26 October 2016

# Presentation structure

- IEA Clean Coal Centre introduction
- Need for flexible operation of coal plants
- Outline of requirements and technical means to achieve flexibility
- Summary



# The IEA Clean Coal Centre



Austria



Australia

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Thermal Coal

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DEWA



Doosan



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GE Power



We are an international organisation, endorsed by the International Energy Agency. We provide independent, objective information on how to use coal more effectively, efficiently and cleanly, to minimise its environmental impact while providing cost effective energy

## IEA Clean Coal Centre activities

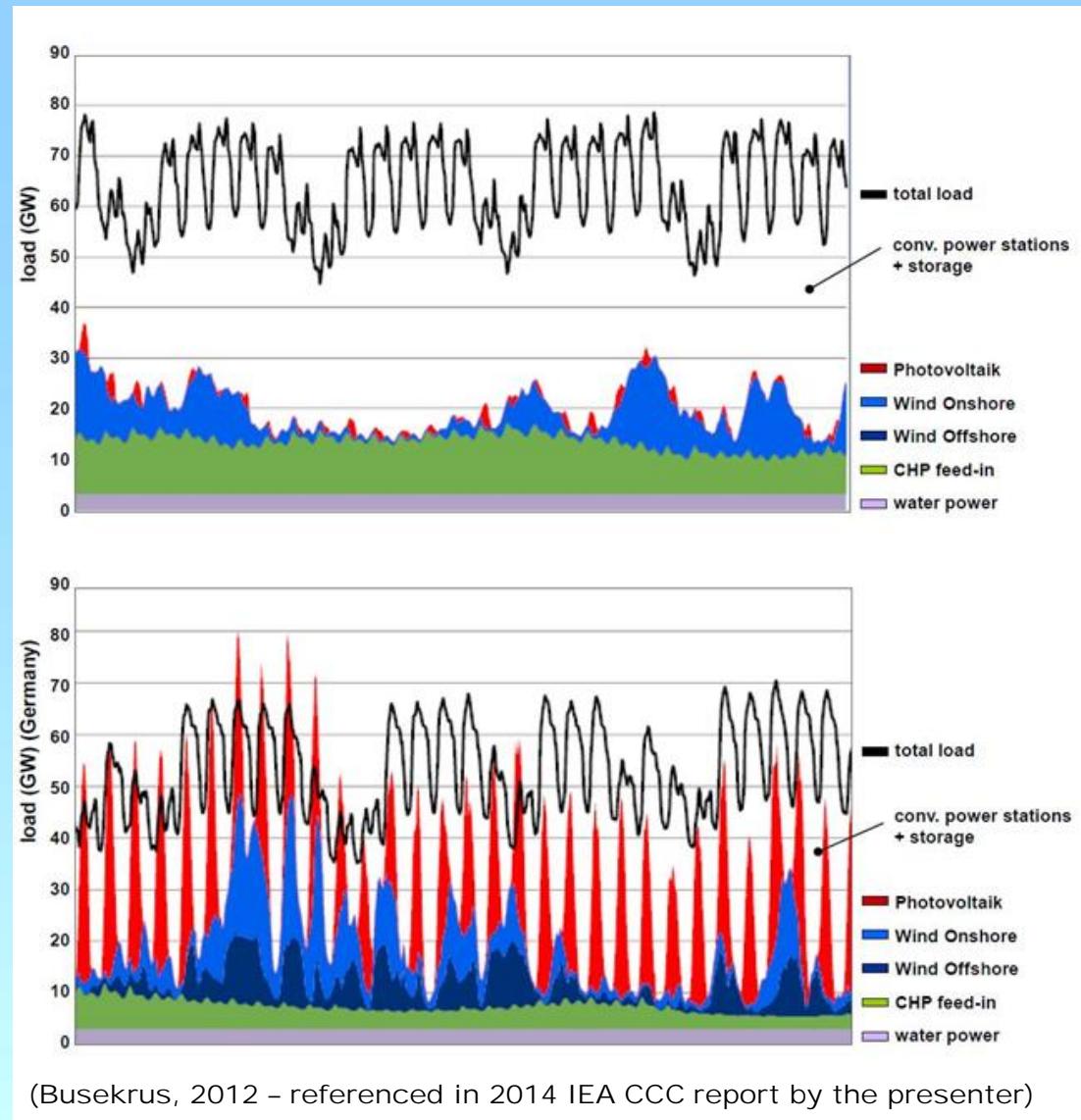
- IEA CCC output includes:
  - comprehensive assessment reports on all aspects of clean coal technology
  - webinars based primarily on the assessment reports
  - technical workshops on key clean coal issues
  - Clean Coal Technologies conference series
  - web based dissemination services
  - capacity building activities in developing countries and industrialising nations, with knowledge transfer on coal related energy and environmental issues

## Flexible operation – the challenge

- Electricity output from wind and solar renewable units fluctuates and these plants are among the first called to generate
- A rising proportion of these renewables is reducing the inertia of grids, presenting challenges for stability and security of supplies
- Coal and gas-fired power plants are having to operate at highly variable load and turn on and off to keep grids stable
- The situation is currently most applicable to Western grids but will apply elsewhere in future until new large scale energy storage become a reality

## An example

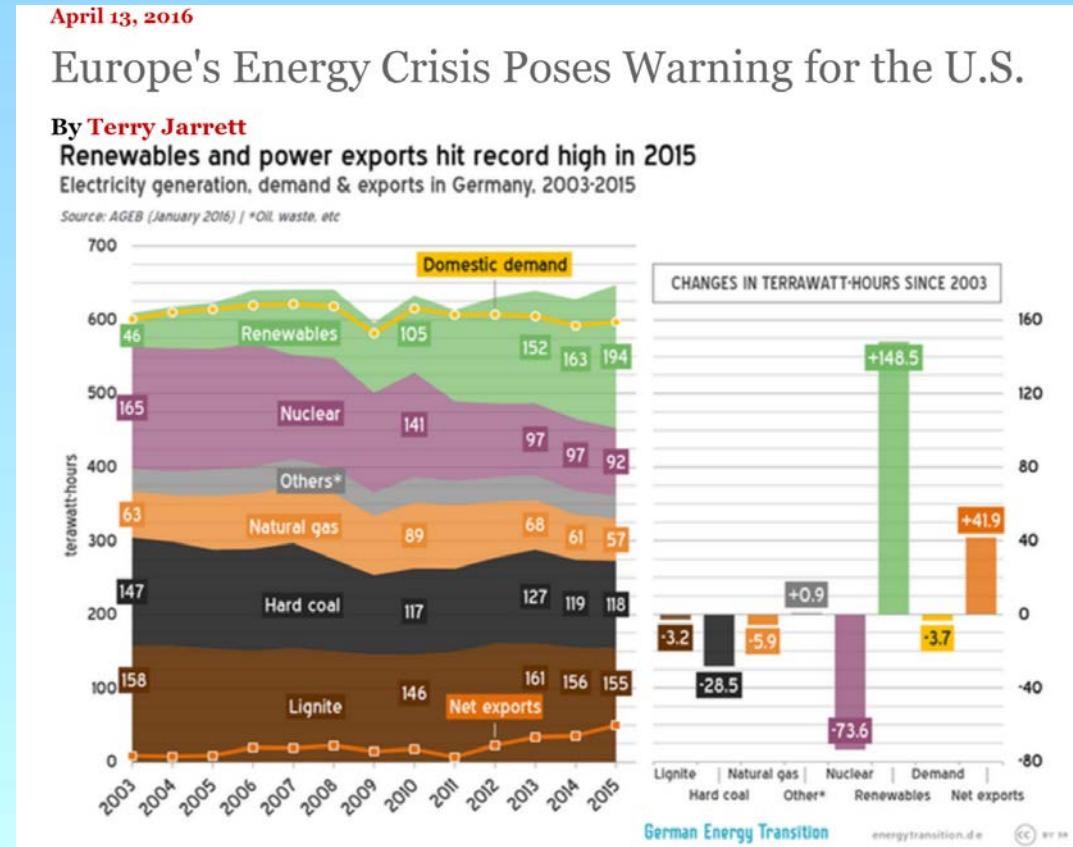
- These graphs, from Hitachi, compare the monthly pattern of load and generation for Germany in 2010 (upper) with a prediction for 2020
- The coal units have to be able to change in output very quickly to balance supply and provide more frequency control
- Typical ramp rates of 2-5%/min older PCC units necessitate improvements



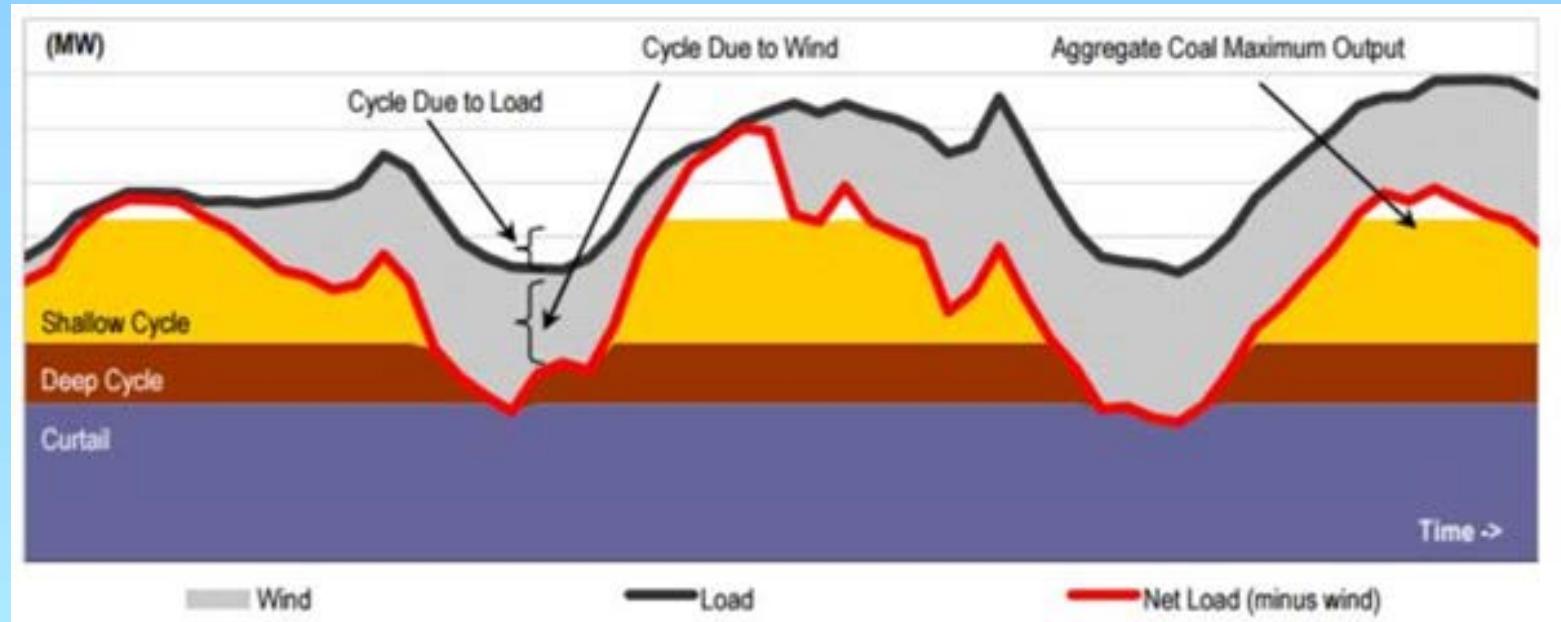
(Busekruš, 2012 – referenced in 2014 IEA CCC report by the presenter)

# The trend to renewables

- Again, using the German example, the trend is dramatic
- The changes over the twelve years to 2015 are shown here

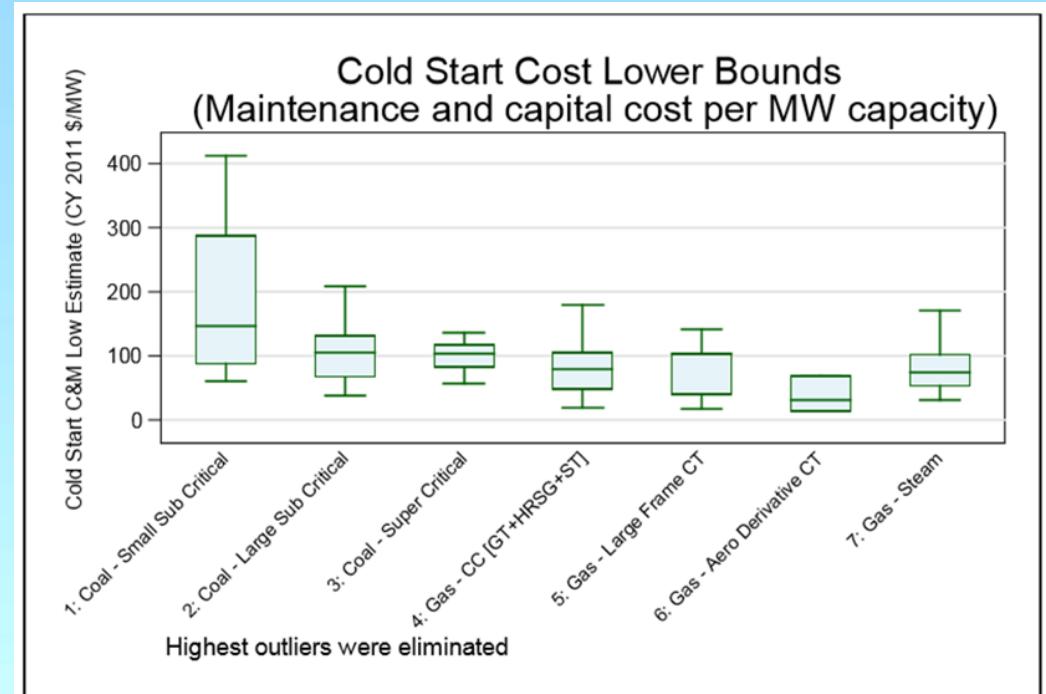
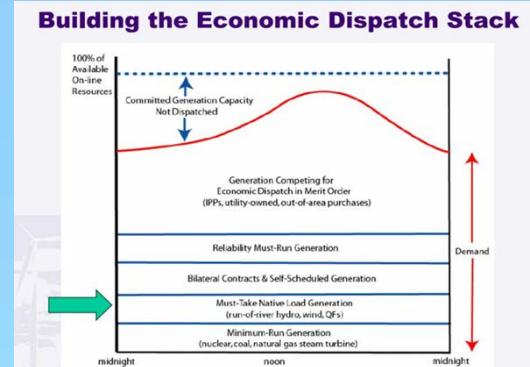
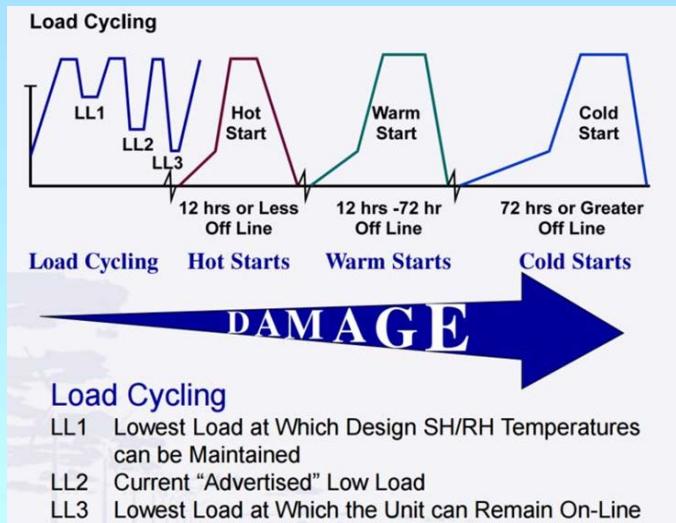
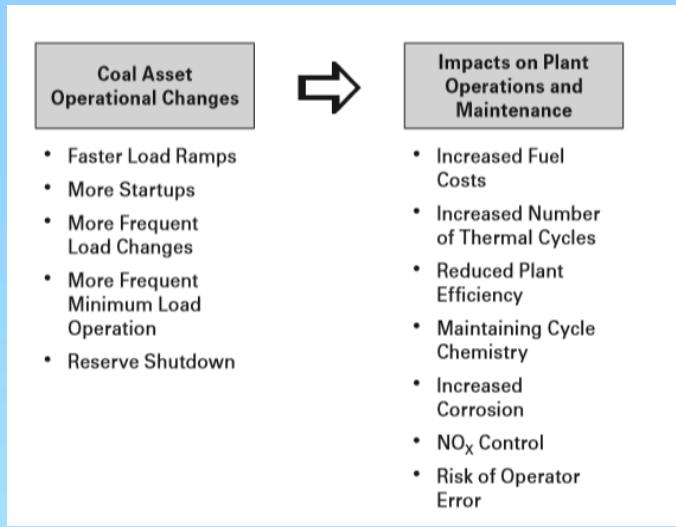


# Impact of wind on coal unit cycling



This slide (data from the Public Service Company in Colorado, USA) shows coal plants ramping and shutting down to fill the gap in demand left by fluctuations from the intermittency of wind power production in the region

# Implications of cycling and variable load operation



# Requirements

- Greater resilience for high availability
- Capability of fast start-up and rapid ramp rates
- Means to meet wide load range
- Reduced minimum output capability to minimise need for shut-down (damaging and expensive)
- Maintenance of efficiency as far as possible
- Maintenance of emissions compliance
- For retrofits and new plants
- Provision of frequency control

## Approximate cost of starting up a coal unit

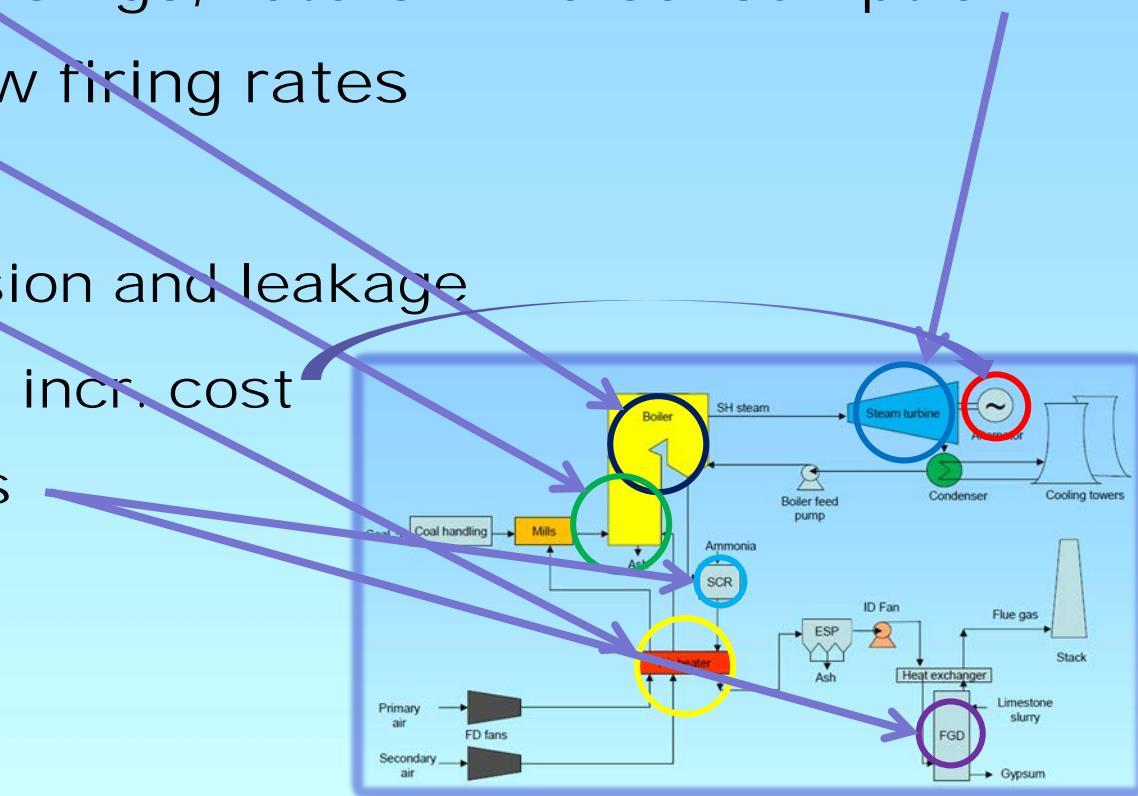
- Cold start – off >48 h; start-up 7-15 h – \$100,000-350,000
- Warm start – off 8-48 h; start-up 3-6 h – \$5,000-6,000
- Hot start – off <8 h; start-up 1-3 h – \$4,000-5,000

## A spreading problem

- Renewable power units are being installed in many parts of the world. For example
  - China is projected to have, by end of 2016, 120GW of wind, 43 GW of solar, and 320 GW of hydro power (NEA, reported by Bloomberg)
  - India has plans for 100 GW of solar power by 2022 (WSJ)
  - Many other countries are interested in increasing their wind or solar capacity
- In many of these countries, coal will remain, with gas, important in supplying significant power, so flexibility will be needed in these plants until new large scale energy storage become a reality

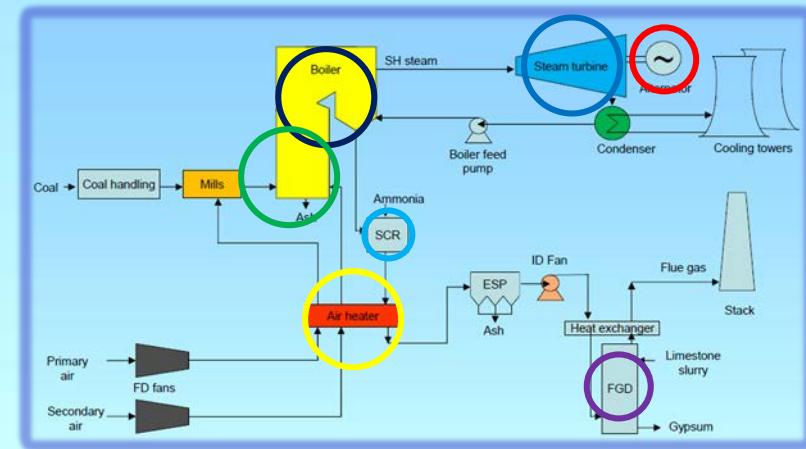
# Plant areas affected in operating flexibly

- Boiler tubes, ties, headers, membrane walls - life consumption from fatigue, creep-fatigue, corrosion, expansion
- Turbine valves, casings, rotors – life consumption
- Achieving very low firing rates
- Other impacts
  - air heater corrosion and leakage
  - lower efficiency, incr. cost
  - higher emissions



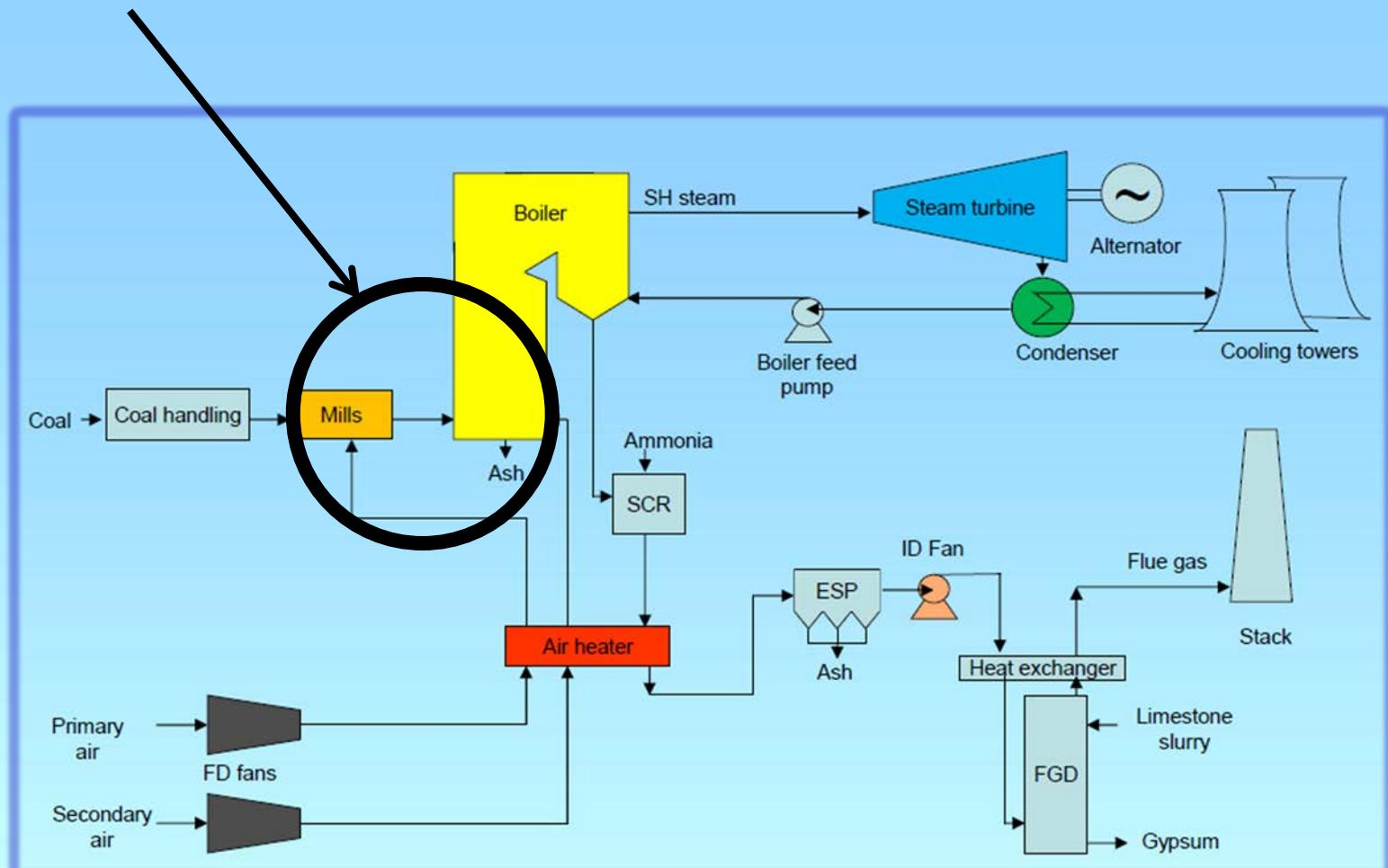
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- **New systems improve flexibility and reduce adverse impacts**



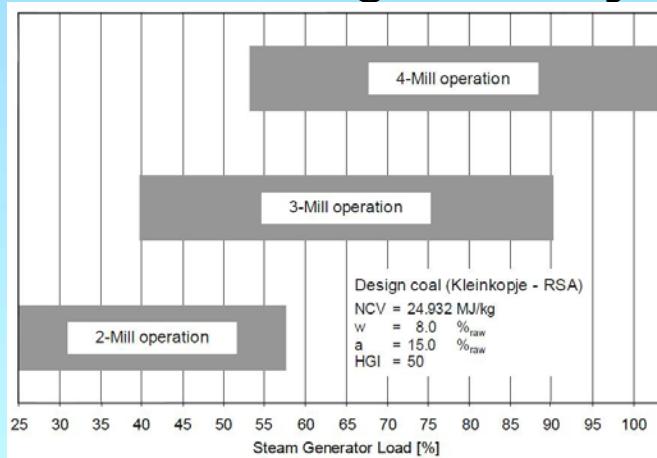
# Challenges in operating flexibly – combustion systems

Firing down to very low rates



# Firing systems – bituminous coals

- Range of operation without support can be extended to lower loads by:
  - Mill size and burner changes – loads down to 25% on two mills
  - Loads even of 15% on one mill achievable in corner-fired tangential systems, as at Heilbronn Unit 7

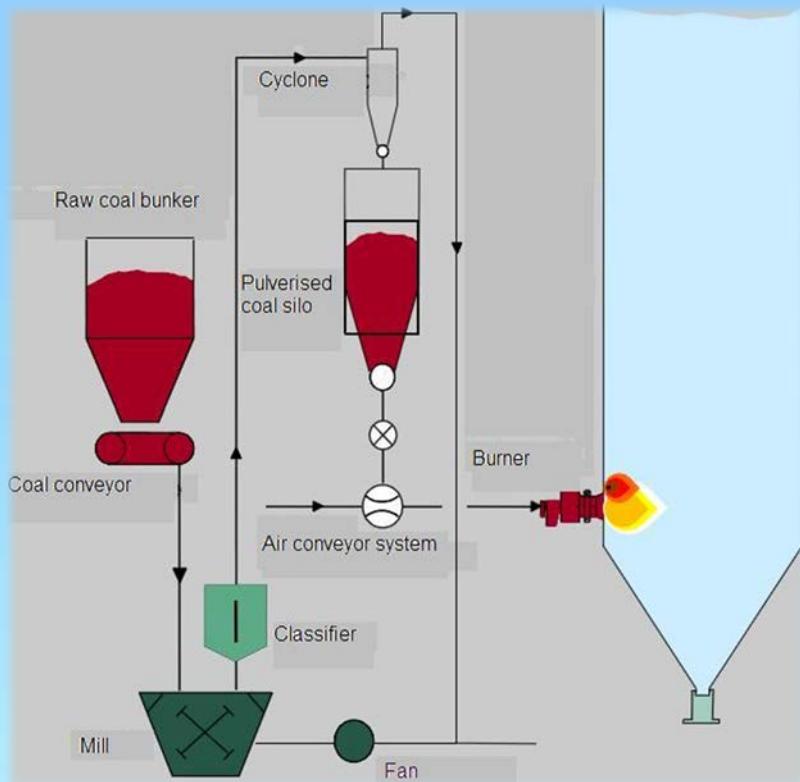


Burner operating range - design with four mills for hard coal (Brüggemann and Marling, 2012)



Heilbronn power station, Germany  
Photo: Kreuzschnabel Wikimedia Commons

# Firing systems – indirect firing

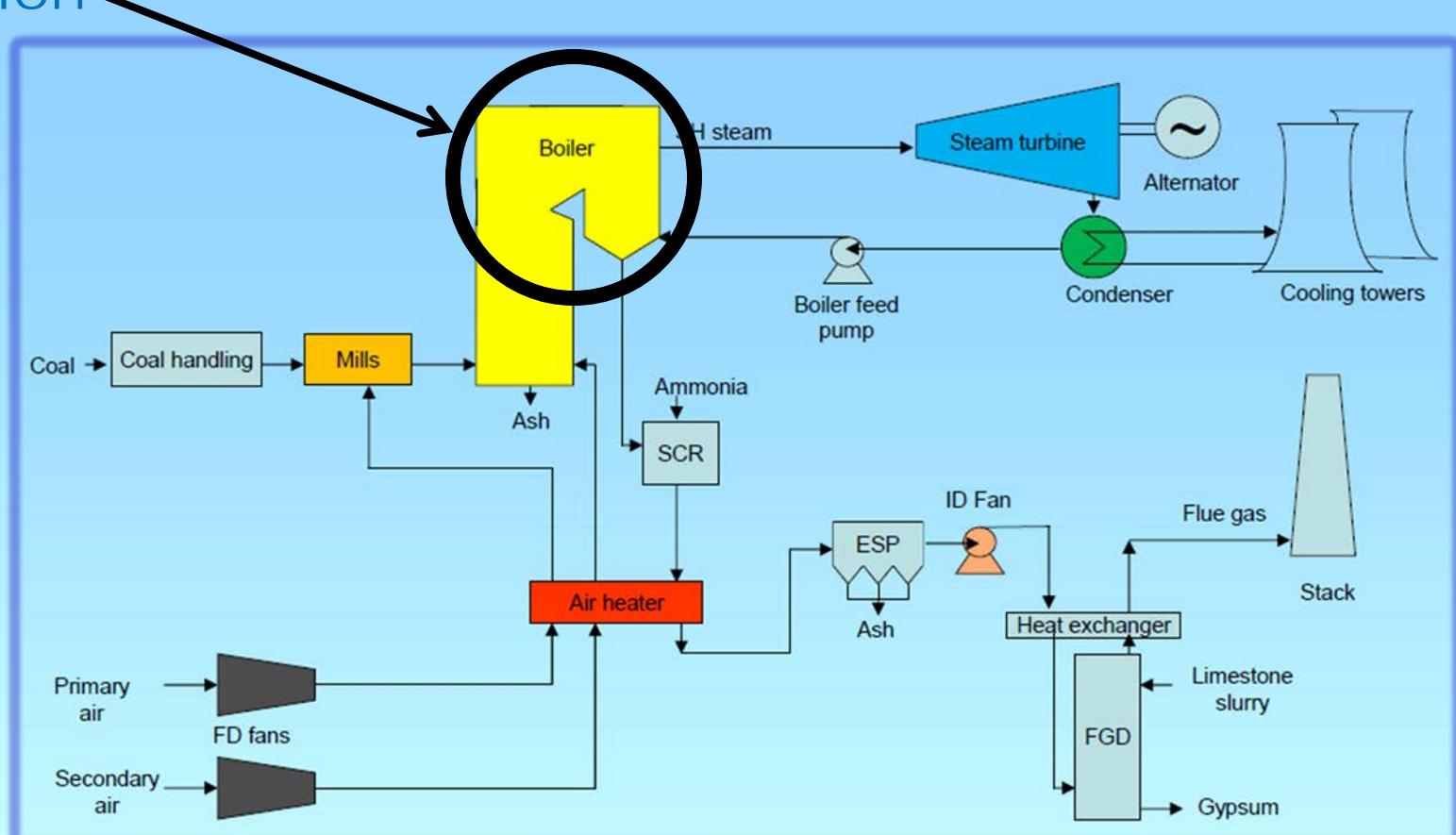


Indirect firing of pulverised coal  
(Busekrus, 2012)

- Indirect firing can achieve 10% load or even lower
- Reduction in inertia of system allows firing ramping up to 10%/min

# Challenges in operating flexibly – boiler components

Boiler tubes, ties, headers, membrane walls – life consumption from fatigue, creep-fatigue, corrosion, expansion



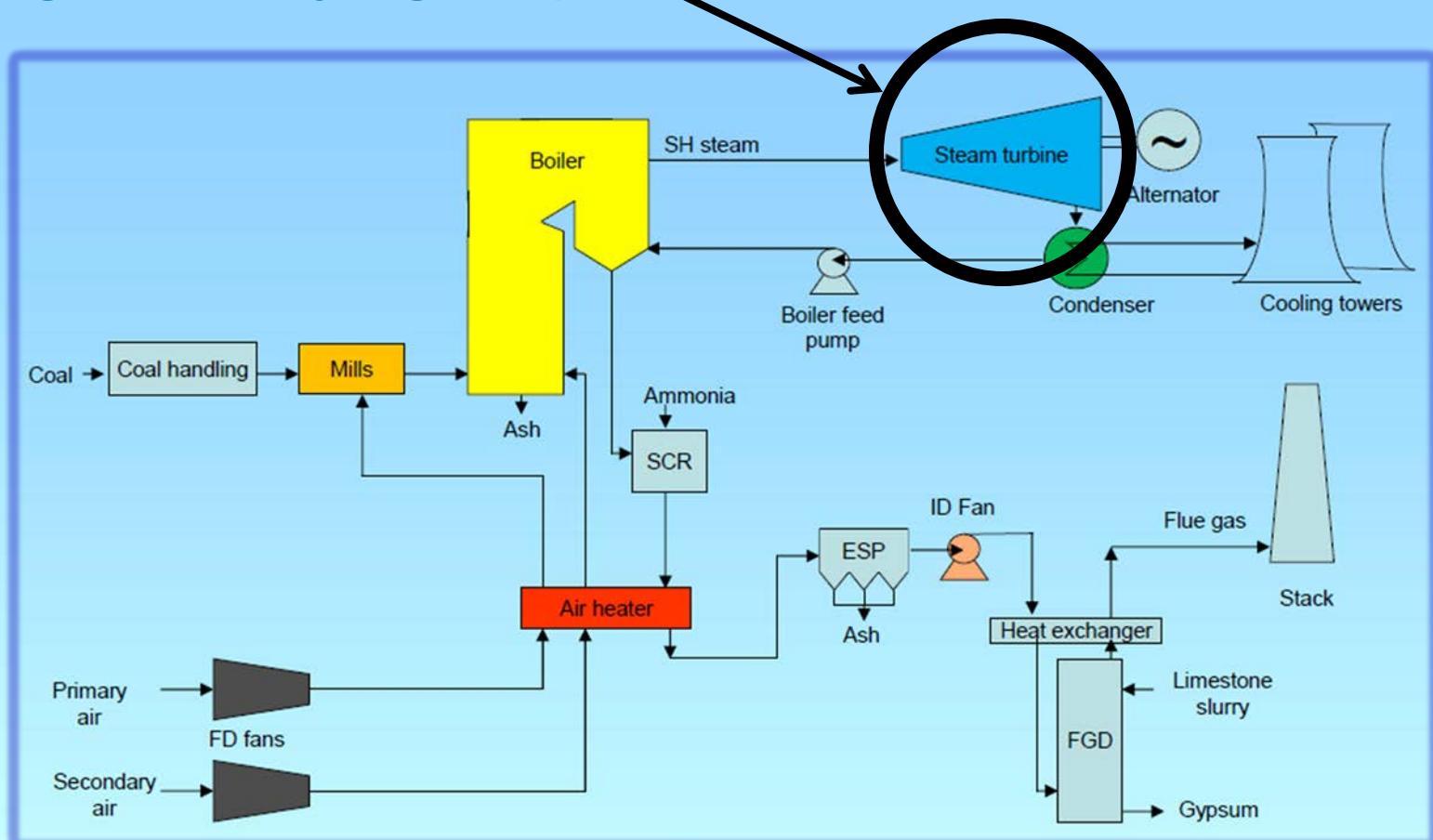
# Boiler pipework – improvements for greater flexibility

- Increasing ramp rate through reducing thermal gradients by:
  - Using new steels to allow reduced metal thicknesses
  - Increasing number of headers
  - External steam heating and hot storage systems
- Reducing the minimum load by, for example:
  - Evaporator design, such as rifled tubing in new boilers
  - Economiser or feedwater heater bypasses



# Potential issues in operating flexibly – turbine

Turbine valves, casings, rotors – life consumption and achieving fast varying output



# Turbine and water/steam systems – achieving greater integrity

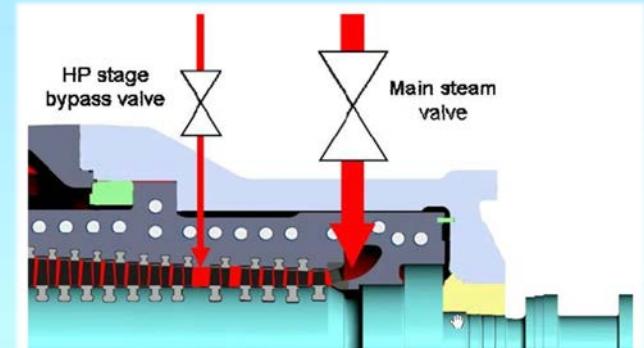
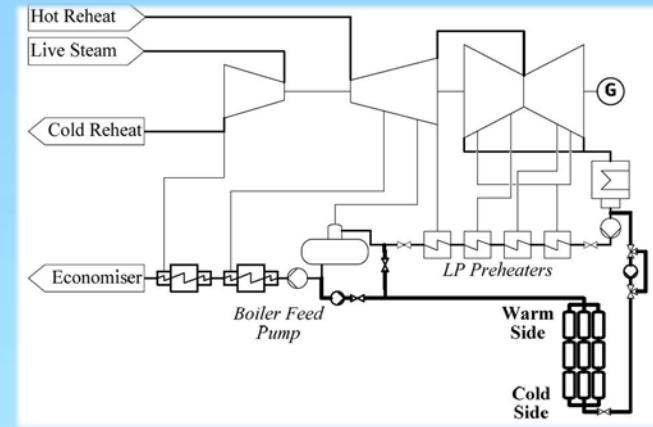
- Features available for faster response, greater resilience and reduced losses include:
  - Steam cooling of thick-walled outer casings
  - Use of sliding pressure (whole plant aspect)
  - Turbine bypass, so rate of steam temperature change can be managed during start-up and shut-down
  - Advanced sealing and other measures to ensure correct clearances during cold start-up



USC steam turbine at J-POWER's Isogo Unit 1, Japan

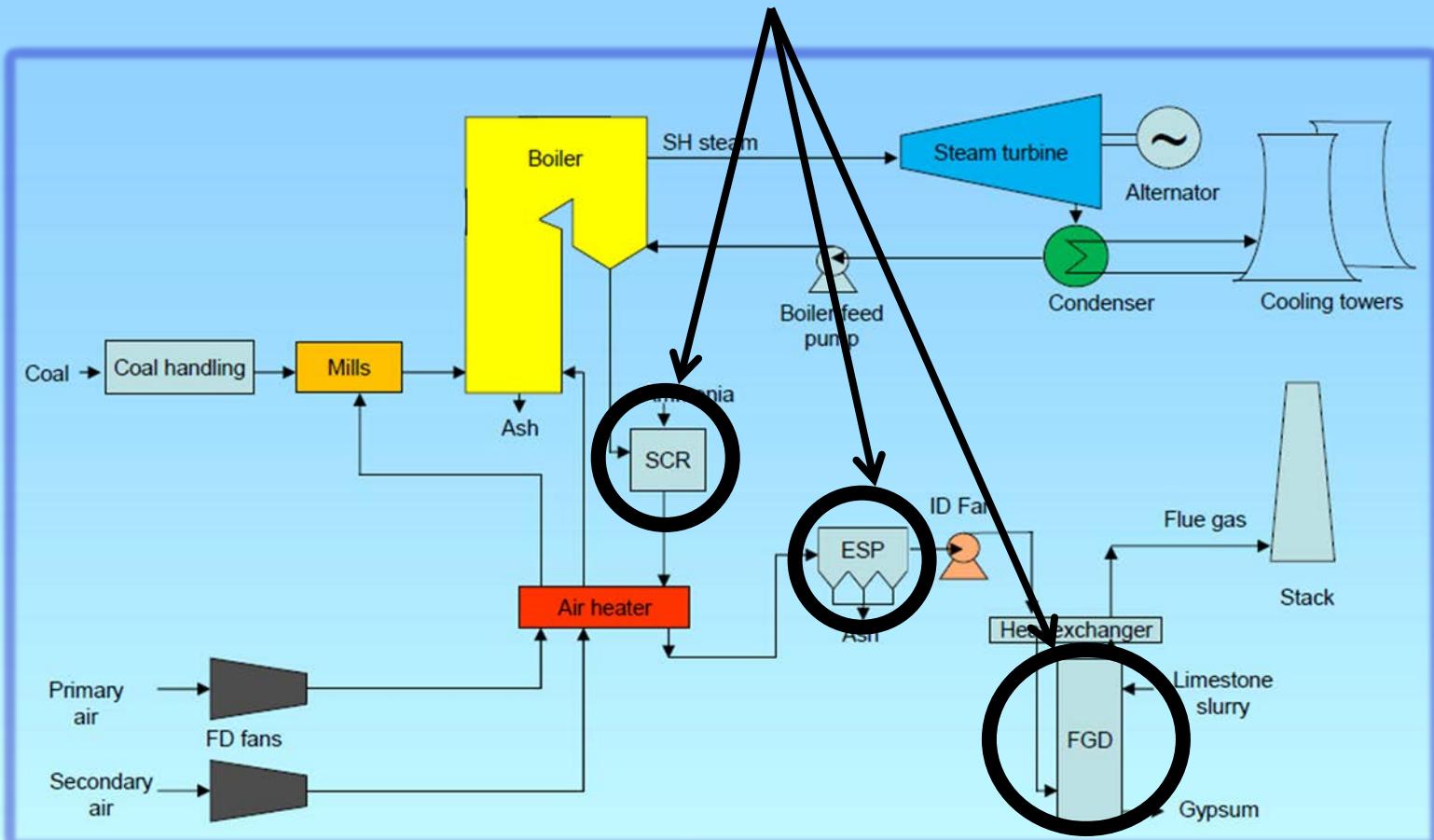
# Turbine and water/steam systems – achieving flexibility

- Methods for short-term additional power and frequency control:
  - Turbine throttling, condensate throttling
  - Feedwater heater by-pass
  - Thermal storage (feedwater tanks with hot and cold water displacement)
  - HP stage by-pass for frequency control over whole load range



# Challenges in operating flexibly – emissions control systems

Systems can be affected by off-design conditions



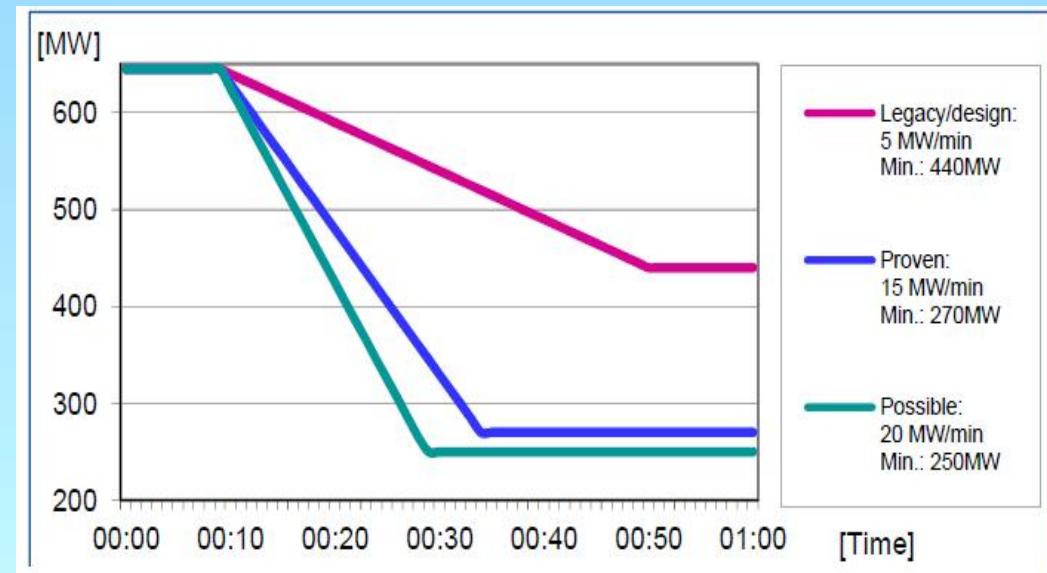
# Emissions control systems

- These need to be able to cope with load swings, low loads and shut-downs
  - SCR: needs to be at correct temperature to prevent catalyst blocking and harm to airheater. **Solutions:** economiser by-pass, heating facilities, baffles
  - FGD needs sophisticated control; shut-downs are unwelcome; liquid/gas ratio may need to be increased at lower loads
  - **ESPs and fabric filters** can accommodate rapid load changes provided that temperatures do not fall too low causing moisture to condense



# Control systems (1)

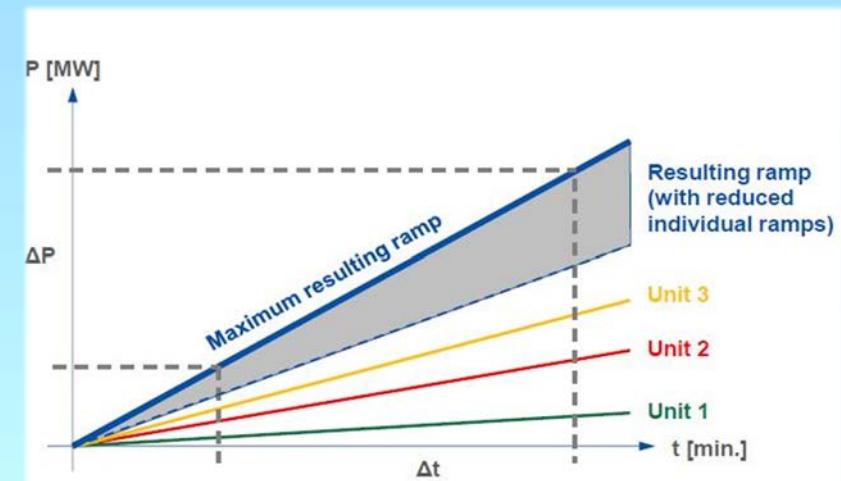
- Generally worthwhile replacing control and instrumentation systems in older plant to increase efficiency and flexibility
- Such retrofits can give faster ramp rates and lower minimum loads



Improvement in minimum load and ramp rate of 600 MW lignite units by fitting new control systems (Eichholz and others, 2013)

## Control systems (2)

- Modern control system retrofits can also give:
  - Stabilisation of non-stable loops from plant ageing
  - Better management of turbine temperatures and clearances
  - Whole-plant self-learning predictive systems
  - Combined operation of multiple units with eventual future remote co-ordination



Using control systems to combine multiple units for greater ramp rates (Schröck and Dürr, 2013)

# Flexibility in other types of coal-fired plants

- CFBC

- Water-steam cycles similar to those of PCC
- CFBCs can be reasonably good at load following, but the boiler arrangement and fuel combustion systems can limit minimum load in absence of supplementary fuel
- The system is less well suited to on-off cycling because of potential for refractory damage and the desirability of keeping the bed temperature close to operating range

Lagisza SC CFBC in Poland



# Flexibility in other types of coal-fired plants

- IGCC plants

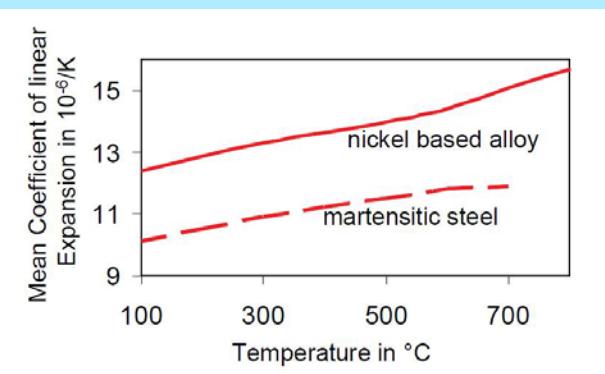
- Flexibility not a targeted design feature to date
- Minimum load typically 40 - 50% of MCR
- Ramp rate similar to that of many older PCC units
- Studies have been carried out based on using syngas or oxygen storage or polygeneration
- If IGCC plants start to be ordered in large numbers, designing for flexibility will become more important

Edwardsport IGCC, USA

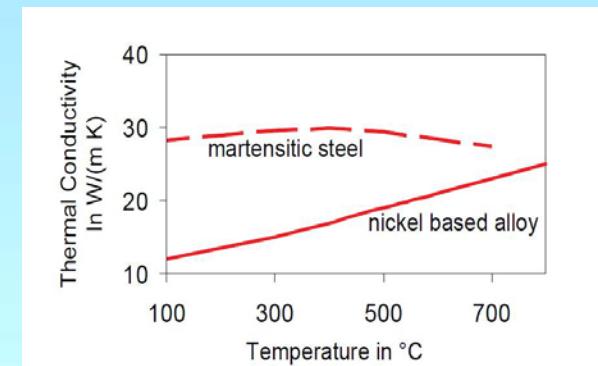


# Flexibility in other types of coal-fired plants

- A-USC plants
  - There are programmes around the world to develop these high temperature (700C+ steam) PCC plants
  - They will include advanced nickel-based alloys
  - None have yet been built, so laboratory tests and studies are all that we have for flexibility assessment
  - Low thermal conductivity and high expansion coefficient of the superalloys are potential issues



Properties of a nickel alloy  
and a martensitic steel  
(Gierschner and others, 2012)



# Flexibility in carbon capture coal-fired plants

- Some CO<sub>2</sub> capture plants may be able to operate at base load, but others will need to operate flexibly as renewable plants will be called to operate first
- A number of possible ways of achieving flexibility are being studied:
  - Storage of spent solvent in post-combustion scrubbing-fitted plants
  - Oxygen storage in IGCC and oxy-fuel CCS plants
  - Hydrogen storage or polygeneration in IGCC CCS plants

# Summary

- Varying output from renewable energy plants is forcing fossil units to operate very flexibly
- Coal will be competing with gas for providing rapidly responding output and can meet the challenge
- The main technical needs are capabilities for rapid start-up, fast load following and grid frequency stabilisation
- Potential life-limiting effects of plant cycling are known and new or retrofitted systems can give high flexibility with good plant life and efficiency
- It is not known for certain how much flexibility A-USC or IGCC plants could ultimately achieve, but it may be possible to exploit the energy storage potential of IGCC
- For CO<sub>2</sub> capture plants, a number of possible ways of achieving flexibility are being explored in concept

# Coal-fired power plants – flexibility options and challenges

For free download of reports go to [www.iea-coal.org](http://www.iea-coal.org), register and search under Publications, Final Reports:  
Increasing-the-flexibility-of-coal-fired-power-plants, CCC/242  
(Colin Henderson, 2014)  
Levelling-the-intermittency-of-renewables-with-coal, CCC/268  
(Lesley Sloss, 2016)

Thank you!

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